AN INTEGRATED DISPLAY AND CONTROL SYSTEM FOR MAN-MACHINE COMMUNICATION

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Captain, United States Marine Corps

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the requirements for the degree of

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ABSTRACT

Computer oriented systems have created the need for a closer interaction between men and computers. This thesis is an evaluation of, and the resulting system design of one such system. The main portion of the design is that of the operator's display and control console for this system. Included as a portion of the design problem is a computer program for the mechanization of wiring data for constructing the digital equipment.

The operator's display and control console is presently being constructed by Data Display, Incorporated of Saint Paul, Minnesota.

The author wishes to express his appreciation to Professor Mitchell L. Cotton of the U. S. Naval Postgraduate School, and to Mr. G. N. Grashorn of Data Display, Incorporated for their many helpful suggestions.

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1. Man-Machine Communications in a Digital System

The present use of computers in most applications can be classified as one of two categories:

a. Off-line operations in which a preformulated problem and precoded groups of data are fed to the computer along with the programs for processing the information. The computation then proceeds according to the preplanned program, if all data and programs are correct. Upon completion of a successful program, the desired results are then dumped from the computer memory to an output media for printing and evaluation at some later time. The extension of this technique has led to the "closed shop" computing center with their various "auto-monitor" programs in which the individual who wants the problem solved never sees the computer. This technique was prompted by the expense of large digital computers. The major drawback to such a scheme is that in writing new programs or trying to formulate new techniques for solving problems, there is a good chance for errors which will not allow the program to run to completion and may not give any indication of the reasons for stoppage. The cost of off-line formulation and "de-bugging" may be considerable in some circumstances.

b. On-line operations in which the operator is working in real time with the computer on a real time physical problem. This type of operation traditionally employs programs which are necessarily complex to take every possible situation into consideration. The role of the man in this system has been to make simple "yes-no" or similar decisions and to provide a means of accomplishing tasks

which are not automated or programmed whether by reason of difficulty or just oversight. Examples of on-line operation are the military systems (i.e., SAGE, NTDS, etc.) and industrial process controls. The cost of such systems are large as the computer is usually in full time use by the system due to the special purpose nature of the equipments.

There has been a recent trend to explore the possibilities of utilizing the best points of both techniques in systems linking man and computer more closely /1, 2/. In order to accomplish this, the basic class of operation must tend toward on-line operation. By having a closer link with the computer, the operator can make decisions at various points in the process based on real time feedbacks; examine changes in results due to varying inputs or parameters in real time; program and check blocks of codings easily before integration into a more complex program; and call up and inspect large blocks of information randomly from a large memory.

In order to accomplish this interaction between man and computer while keeping the overall system flexible and relatively inexpensive, certain requirements must be met: (a) A method of time sharing of the central computer must be implemented whether by programming or hardware techniques. (b) Display and control equipments must be designed to allow the operator to effectively communicate complex ideas to the computer and to allow the computer (through proper programming) to make requests on or display data to the operator. The first requirement is dictated by the desire to perform on-line and off-line computations interlaced in

time, while the second is essential to any closely coordinated man-computer system. The specifications of time sharing systems have been developed in recent literature /28, 29/. It is the purpose of this thesis to develop design criteria and to carry out the design of a display and control console which can be applied to many different type problems.

In a computer oriented system the flow of information is as shown in Figure 1-1.

The man-computer interface consists of two unique parts. There must be a provision for the operator to communicate his desires to the computer, and the computer should have the provision to display results or ask for further instructions. Specific techniques for accomplishing these functions will be discussed in Chapter 2.

In order to intelligently use any or all of the possible information available in a complex system, the display must be able to select various portions of information readily and easily. This means that the display console itself should be a complex buffer and should be able to control the computer's memory and programs. The main control programs in the central computer should be tailored to the display which in turn should be tailored to the human requirements for ease of operation along with flexibility.

Display updating may be done on any of the following criteria:

a. Upon receipt of new data by the computer

b. Upon a real time interval

c. Upon request from the display console

Priority considerations in the case of radar or automatic inputs

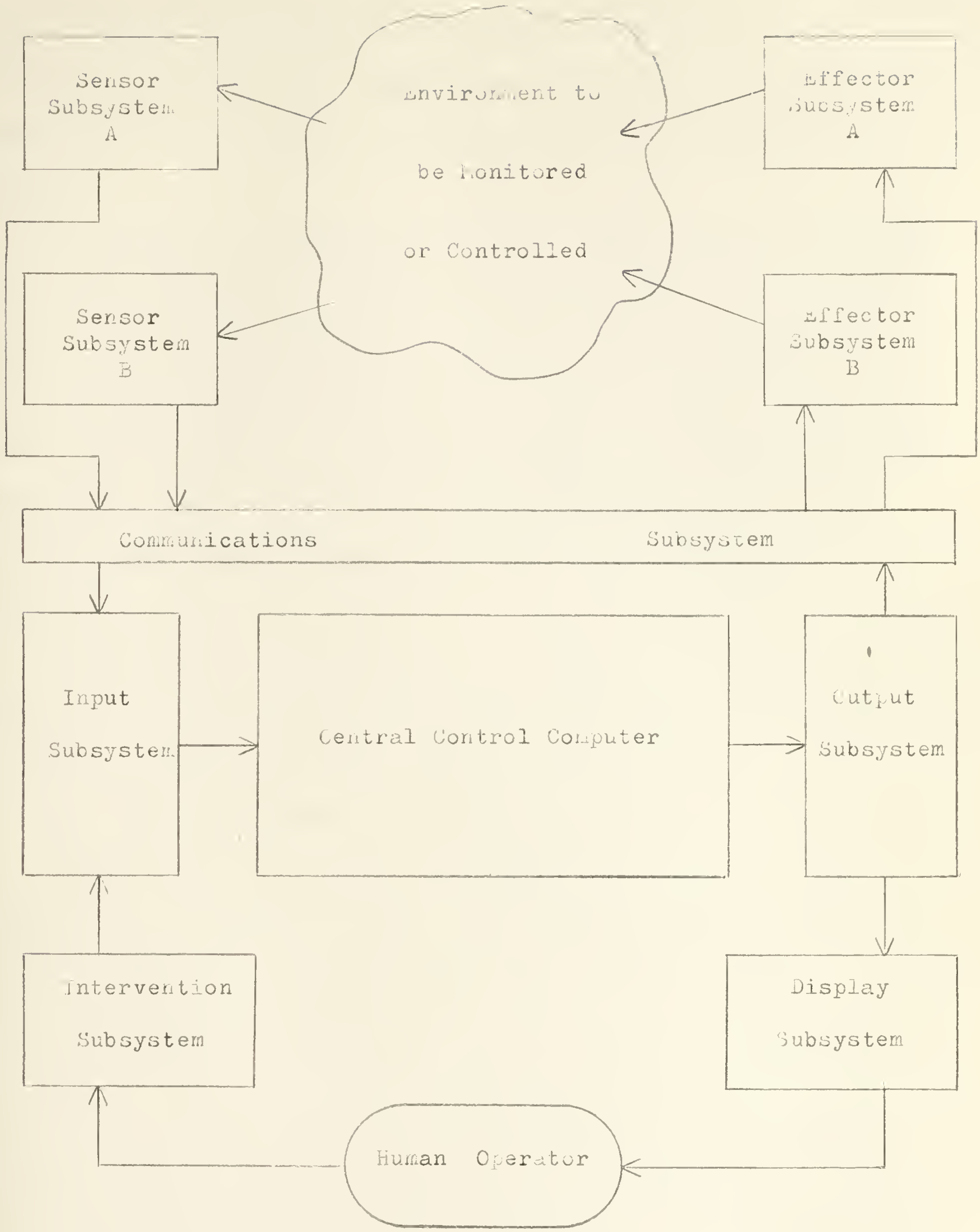


Figure 1-1
Flow of Information in a Man-Computer System

versus manual inputs should also be given consideration in the design of a given equipment. There should be a method for overriding any preselected priority sequence without changing the whole sequence.

The amount of information on a given display must be selectable by the human operator. If there is too much information or unwanted information mixed with the desired information, he must be able to remove some portions of the overall display or be able to expand a part of the display on a secondary display. He should also have control over selective portions of the display in order to view tabular or other information at the same time a graphical display is being produced.

All of these factors should be considered in the design of a given man-computer system with the main guide lines of the actual computer characteristics with which it is to operate.

The broad requirement for an input device is that an operator can readily adapt to it and can communicate his desires to the computer in an efficient manner. This requires that the device be designed using a minimum of controls, but with each control uniquely labeled and preferably able to call in a sequence of subroutines. The general purpose (stored program) computer is well suited for this type approach. By inserting an executive program into the memory, the control keys can be uniquely labeled to call out and execute desired portions of the program. Then, by changing the executive program, the functions of the controls can be changed. So by changing the labeling of the controls with an "overlay", many

special purpose control consoles may be simulated. An additional method for specifying information to a computer is that of allowing the operator to draw lines or symbols on a display surface or some input "sketch pad". An interpretive routine in the computer would then have to perform a pattern recognition, curve fitting, or other similar operation before taking action. One other desired control is closely linked to the display or output device. There must be a method for interrogating the computer about a point, a symbol, or an area on a display for the purpose of obtaining amplifying information about the interrogated portion.

The requirements for a display device are imposed by the user. Some of these are physical requirements based on the constraints of human reaction time and visual resolution, while others are based on clarity or recognition of information /3/. These have been listed with a brief explanation of each.

a. Selective display capability:

The computer can generate and hold in its memory a large amount of display information. The operator can intelligently use only a limited portion of the total supply of data at one time. For example, an aircraft controller may only be interested in traffic within a certain block of altitudes; so, he should be able to call in to the display only the representation of those aircraft within his volume of control.

b. Fast response to commands:

When asking for a new piece of information on a display or when dropping some outdated display, the response to the

command should be fast enough to allow continuity of thought for the operator. He should not have to wait for the command to be executed and the display changed.

c. Number and size of the display devices should fit the usage requirements:

In a large system several individual operators may be needed for specific tasks. This function may best be implemented by using a group of individual operator consoles working on data from a central computer and display generator. In some systems, a group of specialists may want to arrive at an optimum decision based on information on a central display. For this purpose, a large screen display is necessary with a possibility of inputting commands from one or more input devices.

d. The display should not flicker:

The retention of images by the eye is such that if a display is refreshed at a rate of about 30 frames per second, no flicker will result. The flicker of a display will be dependent on the storage time of the display elements. For example, if a long persistence phosphor is used in a cathode ray tube display, the refresh rate requirement is reduced, but the time required to change the position of any point on the display or the whole display is determined by the decay time of the phosphor. This decay time is dependent on the initial intensity of the display.

e. Resolution of the display should be greater than the resolving power of the eye:

The eye can discriminate parallel lines separated by

intervals equal to the line width to a value of 60 lines per degree. So for a single operator console, if the display surface is considered to be the base of an isosceles triangle and the eye to be the apex of this triangle (actually an isosceles cone), approximately 50% of viewing angle is included. This dictates that the display should have at least 2,000 "bins" for unique storage in each direction. To place this into a digital representation for computer generation the resolution should be at least 11 bits.

f. The contrast and brightness should be such that under ambient light conditions, the operator will not be subject to eye strain:

The intensity difference between background and information should be on the order of thirty to one for normal usage. If the ambient light is high, reflections from the display surface tend to "wash out" this contrast. A cathode ray tube display console that is designed to operate in normal room lighting needs to incorporate a fast phosphor that can be raised to a high intensity level without producing an extended decay time.

g. Accuracy and distortion should be reduced to an acceptable level:

In any display system, the ideal resulting display would have perfect registration and focus at all points of the display. This goal is rarely, if ever, attained due to hardware considerations. For example, in a cathode ray tube display there is a definite defocusing effect at the edges of the tube as the path length of the electron beam is longer. Also, the voltages to pro-

duce the desired deflections in an electrostatic deflection tube (or conversely the current to produce deflections in an electromagnetic deflection tube) do not vary linearly with the distance from the center of the tube /4/. This leads to the use of compensation circuits in the control circuitry which can reduce these conditions to an acceptable level.

h. The coding should allow for a variety of presentations:

The requirements for flexibility encompass such ideas as color, size, shape, intensity, position and orientation. And blink rate as a means of attracting attention. Most displays require a set of symbols for normal usage. These would be numbers, the alphabet, and any frequently used symbols. In addition, a method of generating lines should be included for forming special symbols or line drawings. These "vectors" should allow for blanking portions of the length while proceeding along a given direction to enable the further coding of lines into dashed lines.

i. The format for the display should suit the usage requirements:

Some examples of formats are textual, tabular, graphical, situation or overlay map plus defining symbols, line drawings and diagrams, patterns of symbols to show complex situations, and pictorial symbols to show the status and condition of remote elements. The general classification can be termed either fixed or free. The fixed format is considered to be a textual or tabular type where automatic incrementing and positioning of symbols is accomplished on a set of constraints mechanized into the hardware.

The free format is usually implemented through a program control feature which must be generated in the computer.

The number of operators and/or viewers of a man-computer console has a direct bearing on the requirements as has been previously noted. For group displays, optical projection and electroluminescent panels have come into usage as the size of direct view cathode ray tubes are limited by deflection techniques. Examples of group displays have been discussed in recent publications /5, 6/. This thesis will discuss only single operator, direct view, non-colored cathode ray tube displays.

2. Techniques for Man-Computer Communication

The methods available for producing commands to a computer are largely dependent on the type computer being used in the system. For normal communications the computer is in control of the data lines, and the executive program must sample the possible inputs at "programmed" time intervals. For priority communications, the operator should have the ability to interrupt the computer and insert the necessary commands. The nature of any input to the computer is one of a digitally coded bit pattern dependent on the setting of switches or digital encoders, and the initiation of a command switch. A good example of this type communication is the console typewriter which can be used for input and output. An exception to this straightforward input technique is that of employing a 'sketch pad' in which the input takes the form of movement of a probe over a display or an analog surface. In these cases, the computer must sample the allowable surface at a rate fast enough so that normal motion of the probe by the operator generates a smooth input of coded positional values corresponding to the desired lines being traced by the probe. In the case of a direct view cathode ray tube, the probe is a light sensitive photo-diode, and the computer program must display a raster of points about the last recorded position of the probe. The new point is recorded as a feedback of information of the position in the raster which coincides with the probe.

In order to produce a visual display on a cathode ray tube surface from a computer output, a certain amount of decoding and

processing must accompany each computer word. Principle requirements by the display device for each piece of information displayed are: (a) positional information, i.e., X and Y or ρ and θ with respect to some reference point; (b) coded information specifying character or line type, intensity, and size of symbol or length of line. The display circuitry must be able to decode this information and convert its meaning into the necessary deflection and intensity signals to produce the desired symbol at the specified location.

The symbol formation signals must be superimposed upon the positional deflection signals. This can be accomplished by voltage or current summers in the analog deflection circuitry. The methods of categorizing the various techniques for symbol generators have been listed in recent publications /7, 8, 9/. These are dot pattern, scanning raster, waveforms or strokes, and shaped beams.

In the dot pattern method, the symbols are made by positioning the beam to a sequence of positions defining the symbol. At each point in the sequence the beam is unblanked. The result is a group of dots oriented to form the desired symbol. The formation may use a cell of computer memory for each point displayed as in the PDP-1 console display /10/. This method is limited in speed to the speed of each memory cycle. An analog method for generating the dot pattern has been devised which makes use of resistor networks /11/.

A combination of scanning and the dot method are used by the Laboratory for Electronics in their S[illegible] symbol generator. For this method each symbol in the set is represented by a selectable

matrix of magnetic cores. Each core is located at a position where a dot is to appear in the character. The matrix is scanned by rows while the beam is unblanked as a function of the cores.

A variation on the core scanning system is the VIDIAC /12/. Each symbol is again represented by a selectable matrix of magnetic cores. In this generator, the cores are positioned so that they make a double outline of the desired character. The selected matrix is then scanned by rows, and alternate cores turn the beam on and off. This causes the figure to be made up of a group of parallel line segments.

The scanning method of forming characters can be implemented by using flying spot scanner techniques /13/. In this method a fixed size scanning raster is moved to a spot on the generator tube which coincides with the desired character on a symbol mask. The portion of the beam that goes through the mask is focused on a photomultiplier, and this signal is amplified to control the intensity grid of the display tube. The scan pattern must be superimposed on the positional information for deflection signals. The combination of intensity and deflection produces the desired symbol on the display.

The stroke method has been used with much success in the "Calliscope" of Lincoln Laboratories /14, 15/, the symbol generator of Strand Engineering Laboratory, and the symbol generator of Data Display, Incorporated. The methods of deriving the deflection and intensity signals for each of these techniques vary considerably, but the results achieved are the same. The symbols are formed by

unblanking the beam at a starting point for each character and then moving the beam while it is unblanked. Some complex symbols require multiple unblanking and blanking during the formation period.

The shaped beam method is used extensively in the military display systems (SAGE and NTDS). The basis of the system is the "Charactron" tube /16/. The tube has a character matrix within the tube envelope. The character desired must be selected by positioning the beam to the associated figure in the mask by a small electrostatic deflection system. The beam is purposefully defocused to obtain a large cross-sectional area, and the shaped beam that gets through the mask is in the outline of the selected symbol. This shaped beam is then magnetically deflected to the desired position on the display surface.

A comparative analysis of these systems has been accomplished by Lowe, Sisson and Horowitz /7/. Two systems not included in this analysis are the "Strand" generator and the "DDI" generator. The respective times for generating a symbol with these systems are 40 and 6.6 microseconds. These rates of 25,000 and 150,000 characters per second compare very favorably with the other systems.

In addition to computer generated displays on cathode ray tubes, a common method for the computer to convey information to an operator is through coded and labeled lights. These are extremely easy for a computer to initiate, and providing the meaning is clear, can be an economical and efficient way for the computer to alert the operator. The main drawback for this technique is the relative inflexibility of the feedback and the possibility of

operator confusion if there are an excessive number of lights on the control console.

3. Design Specifications

The technical requirements for an advanced design digital control display console for the Digital Control and Automation Laboratory were stated as follows:

> This unit will provide character and symbol display facilities together with provision for direct display of radar video signals. In addition, it will function to provide for communications between an operator and a central computer.[1]

A research and development contract[2] was subsequently awarded to Data Display, Incorporated for the design and construction of the unit which has since been designated as the DD-65. The author worked in conjunction with Mr. Gene Grashorn of Data Display, Incorporated to specify and design this equipment. The remainder of this thesis will be devoted to the actual design of the DD-65.

The system requirements are dictated by the equipments that are to be controlled by or input to the DD-65. There are three distinct modes of operation inferred by the requirements:

a. To input radar information and to provide for (1) display of the video in a PPI format and (2) digitizing of any video return which may be determined to be a target by a detection unit so that the computer may act upon the information.

b. To allow the operator to enter information into the computer.

c. To allow the computer to present data to the operator in the form of symbols on a cathode ray tube or by drawing attention to certain input keys by a system of lights.

[1] M. L. Cotton, Technical Requirements Summary, Digital Control and Automation Laboratory, pp. 1, Feb., 1960

[2] Navy Contract NObsr 59678

The following radar units currently installed are to act as inputs to the system:

AN/SPS [illegible]

AN/SPS 6

AN/SPS 12

AN/SPS 26

These radars are installed in the main radar laboratory, and the following information must be made available for use in the D -65.

a. Azimuth information

b. "Main bang" or time of pulse transmission

c. Video return signal which will have any targets along with noise introduced in the process.

d. Height information in the case of the SPS [illegible] and SPS [illegible].

This analog information must be converted to digital information for display and further transfer to the digital processors.

The digital computers incorporated in the system are a large scale scientific computer, the Control Data Corporation 1604 /17/ and a small data processor, the Control Data Corporation 160 /18/. These computers communicate with external equipment by parallel data transfer lines which are controlled by a sequence of control signals. Also, an essential part of the system is the Control Data Corporation 1607 magnetic tape system which contains circuits for a "Satellite" operation between the 160 and the 1604 /19/.

In order to perform an output from the computers to one of a number of peripheral equipments, the following sequence must be performed:

a. Communications established with the desired equipment (exclusive of all others) by a coded select signal proceeded by a sense signal to determine if equipment is available.

b. Data transferred to output lines, and a signal output ready is sent to all peripheral equipment.

c. The selected equipment (only) recognizes the ready and accepts the data, and at the same time sends an output resume signal back to the computer.

d. The computer, upon receipt of the resume signal, then drops the data and ready signals and prepares for the next word transfer, if any, or merely continues on the internal program.

In order to perform an input to a computer from an external equipment, the computer program must be written so that it looks to see if any equipment has data ready for input. This must be done by coded sense responses which must be built into the peripheral equipments. The computer, upon recognizing the source and the presence of an input word, then sends an input request signal which signifies that it has accepted the data and allows the equipment to drop the signals for its data lines. This sequence must be repeated for each data word entry.

In the 1604 an additional input mode has been utilized. This is the interrupt mode. This interrupt mode must be preselected by a select code in the program. If the selected interrupt occurs during the program, the program sequence is halted at that point. The address at the time of the halt is inserted into the address portion of the upper half of word number seven of the computer mem-

ory, and a jump is made to execute the lower half command of word number seven (note that the 1604 is a single address, two command per word computer /17/). The memory cell number seven should be set up previously to process the interrupt. This coding should place unconditional jump commands in both halves of the word and the address of a prestored subroutine in the address portion of the lower half of the word. This subroutine must be written so that it ends with an unconditional jump to cell number seven. Thus, after having been interrupted, the subroutine is entered, and after processing the interrupt, the control can return to the program step which was being processed at the time of the interrupt.

These then are the physical rules by which the DD-5 was designed to perform its functions of control and display.

Certain other considerations in the realm of flexibility, usefulness and realizability then served to dictate the method of using the basic criteria in the actual system design. These will be listed as a collection of engineering decisions and the reasoning behind them.

<u>The display will have a self-contained memory unit.</u> This requirement is set for the purpose of freeing the computers from constant usage in refreshing the displays. The requirement that the display be refreshed every 30 milliseconds in order to obtain a "flicker free" display is one that is set by the response time of the eye. This dictates that if the display were to display text of 5,000 characters at six bits per character, then the bit rate

would be 900,000 bits per second. The 1604, if only one channel is active, has a maximum transfer rate of about 50,000 forty-eight bit words per second or about 2,400,000 buffered bits per second. The 160 has a transfer rate of about 80,000 twelve-bit words per second or about 960,000 bits per second (unbuffered). Thus, it is seen that the 160 can just barely do the static display at the necessary rate, and if any change is needed in the display, as would be the normal case for moving radar targets, it could not maintain a steady display. The 1604 is not as critical as it has a buffered output, but it still would be taxed in its buffering capabilities if more than a single channel is being used.

The use of a self-contained memory also frees the 1604 from the control subroutines which must be returned to in order to restart a display cycle. This allows more program time for computations. (In a real time air traffic control system with mach one aircraft, the computation times are critical.)

The memory package chosen was a 1024 x 24 bit ferrite core memory, licensed from Control Data Corporation. The size was chosen to compromise between the 12-bit 160 and the 48-bit 1604. The cycle time of the memory is 6.4 microseconds which is less than the 6.6 microseconds required to display a character. This allows a new memory cycle to be completed while the last character of the previous word is being displayed. Thus, for all characters to be painted, the total time involved is:

(6.6 microseconds per character) (4 characters per word) (1024 words per cycle) $\cong$ 28 milliseconds

the difference between the [illegible] milliseconds maximum and the [illegible] milliseconds required for an uninterrupted cycle allows five milliseconds for updating the data each cycle without inducing a flicker.

<u>The intercomputer operation must be selective.</u> In the physical layout of units the Control Data Corporation 1604 and the Control Data Corporation 1607 magnetic tape system are located in the U. S. Naval Postgraduate School computing center on the first floor of the Engineering Building. The Digital Control and Automation Laboratory is located on the fifth floor directly above the computing center. The DD-65 and the Control Data Corporation 160 of this system are to be located in that laboratory. Usage requirements dictate that the 1604 will not be available for use at certain times (pending the incorporation of a parallel processing monitor program). This requires a lockout be available for the 1604. Also, the 160 may be required to do full time processing of radar data for the 1604, and the data flow should be via the 1607 satellite system (159) independent of the DD-65 system. So a 160 lockout is required. The result is the incorporation of a selective mode for using the system.

a. 1604 only (160 locked out)

b. Both (both computers may establish communications with the DD-65.)

c. 160 only (1604 locked out)

This is realized by a mode switch on the logic chassis.

<u>The basic format for display information should be sequential and the display should include vectors as well as characters.</u> The

requirements of a display to designate "where" and "what" for each piece of information displayed would at first seem that a format should be as follows:

X position	Y position	information

The normal usage of information, however, shows that there is usually a relationship between adjacent pieces of information. In the normal typed text or a drawn line that has been broken up into segments, the location of the next piece of information is incrementally connected to the previous one in some manner. The special case would then be taken as the carriage return for the typed text or the end of a line segment in the above examples. So only at these positions would an absolute location be required.

In the case of characters, the normal mode is to increment from left to right. This mode, along with an incrementing from up to down, has been included in the design.

In the case of vectors, several methods were examined. The generation of the vectors is to be under computer control so that any format using simple computations could be used. The following were the three possibilities:

a. Given a starting position, let the computer specify a completely variable ΔX and ΔY.

b. Given a starting position, let the computer specify a limited number of ΔX and ΔY in a coded format.

c. Given a starting position, let the computer specify ΔX and ΔY in 45 degree increments in coded format for a limited number of lengths.

Methods a. and b. both require adders or variable length incremental counters in their construction. Also, method a. needs a completely variable intensity compensation over the line length variations. Method c. needs incremental up and down counters only, but needs counting rate changes and intensity compensation for each length of line to be drawn.

The accuracies of methods a. and b. are greater, but they sacrifice packing density, and they require a greater amount of hardware to construct.

Using this criteria (also keeping a six-bit coded vector package to be compatible with the character coding size), the design incorporated was that of method c., but allowing for an extremely short vector so that the error could be minimized if the accuracy was needed. The use of incremental counters also makes easier the sequential designation of vectors for forming continuous lines.

The requirement for both characters and vectors dictated that a bit be set aside in each string designator word for "mode". The details of display coding will be covered in detail in Chapter 6.

There should be two display tubes, only one of which is a direct slave to the radar inputs. Inasmuch as this system is in part being designed to allow investigation on various digital processing techniques in radar detection, the use for comparative displays is desirable. One display tube must be available to display video information at any time between the "main bang" and the maximum range time (if radar input has been selected). During this time, all display information from the internal memory must be

blocked out [illegible] a [illegible] target. [illegible] limits the amount [illegible] that may be done on this tube. The amount is proportional to the amount of time between the [illegible] and the [illegible] of the next [illegible].

The second tube is independent of the radar inputs and can be used to display processed video with background maps and amplifying information (such as height, [illegible], etc.). This tube is always available to the memory cycle and can be used in conjunction with the direct radar display.

Future displays could perhaps be built utilizing dual beam electrostatic tubes[1] to remove the restriction on time sharing of radar signals and computer displays.

<u>The manual inputs should allow flexibility</u>. The system is designed to be used with a stored program computer, so a large measure of flexibility is accomplished through the use of stored subroutines. The method of calling in a set of subroutines from a magnetic tape library must allow for different sections of the library to be called in for different uses of the console. This is best handled by an overlay which, in addition to [illegible] to designate the overlay, can change the switch function labels by having the function associated with each switch engraved on the overlay board.

[1] Electronic Tube and Instrument Div. of General Atronics Corp., [illegible] - 11 ½ Inch Diameter, Dual Beam, Electrostatic Focus and Deflection Cathode Ray Tube, Sep., [illegible]

In addition to the unique switches, there are a few functions common to all uses of the console. These are treated as a subset of the special overlay function switches, and together they are referred to as keyboard two.

The character keyboard is referred to as keyboard one. This keyboard is made up of all the standard numerals and alphabet, along with special characters to complete the keyboard. These keyboards and their coding will be given full treatment in Chapter 7.

Other manual inputs required are a range switch to control the displayed radar presentation and some method for locating and identifying points on the display. There are two common methods for accomplishing this function digitally:

a. Track ball

b. Photo electric light gun

In the track ball method, two shaft position encoders are placed at right angles, and a ball in contact with both encoders allows the operator (by rolling the ball) to position the encoders very accurately. A symbol will have to be displayed under program control whose center is located at the X, Y position given by the encoders. Thus, by calling for the program to display track ball, the symbol may be centered over any point of interest, and then by a second subroutine this information may be used to enter new information or find a memory cell which contains this point for purposes of changing the display.

The method of the light gun accomplishes the same purpose, but it is positioned by hand over a display, and then the light sensi-

tive circuit is energized and the portion of the tube face under the light gun is illuminated, a circuit can be made to extract the contents of that memory cell to find the position.

The light gun is faster, and its use is a more natural reaction, but for closely spaced points the track ball with its accuracy is easier to use. Based upon this reasoning, a track ball was used in the DL-65.

<u>The display should allow for an auxilliary output channel to dump radar data.</u> In order to obtain best utilization of the computers, i.e., to let them perform computations at a speed limited by the programs (without interruptions for storing data), an auxilliary channel to accept the digitized X, Y (and Z component with minor modifications) has been provided. A buffer memory unit and associated control circuits should be provided between the radar data, and the computer assigned to do the processing. The radar processing computer can then call for targets at its own rate. The buffer memory unit must have a fast access time in order to accept targets at the rate they are received from the radars. The access time needs to be on the order of 100 microseconds if no targets are to be missed. This requirement can be met by designing the buffer unit from standard flip-flop circuits. This is economically feasible as the word size is only 12 bits, and the number of storage words needed should be small.

4. Hardware Consideration and Mechanization of Design Procedure

In order to design digital equipments to have high component packing density and at the same time to allow for easy maintainance, the computer industry has developed the following technique. The circuits to be used are specified in terms of type (pulse or level signal) and speed of response desired. From these requirements, a family of circuits can be designed which are compatible and which, by interconnection, can perform the logical functions <u>AND</u>, <u>OR</u>, or <u>NOT</u>. These circuits are then placed on printed circuit cards either singlely or in small groups. The system designer then need only know the parameters and limitations of the family of logic cards in order to specify the interconnections necessary to design a particular equipment. The construction is then completed by wiring the interconnections on a chassis made up of logic card sockets. In this way all active elements are on the removeable cards to allow for easy replacement of a faulty circuit.

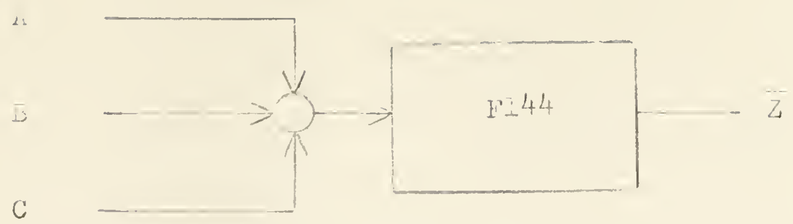
The logic card family used in the design of the DD-55 is mainly the Control Data Corporation type as described in their manuals /17, 18/ and reported on by J. [illegible]. Farrell /20/. These cards are designed to operate at clock rates up to five megacycles as level signal inverters. The switching delay is between 50 and 100 nanoseconds per card. Additional cards have been developed by Data Display, Incorporated for the special uses needed in displays. These are in two main categories: (a) Digital to analog conversion cards for driving the display beams and (b) a fast set of cards to work at about 20 mc for the display of digitized radar information.

he digital [illegible] part [illegible] will not be discussed in this chapter. [illegible] final logic cards are completely compatible with the [illegible] Control [illegible] Corporation [illegible] except for more stringent [illegible] requirements.

The logic circuitry used [illegible]. The basic circuit is an inverter with [illegible] on the inputs [illegible] in such a way that (a) by connecting the outputs [illegible] together at a single input of another card, a logical and is produced or (b) by connecting the outputs of more than one card to a card with multiple inputs a logical or is produced. Figure [illegible] shows the two basic configurations and the symbology used to denote these functions. These basic functions may be combined to enable the designer to realize any complex logical function desired.

This type of logical building block does not readily lend itself to system design using an initial input of only logical equations which are to be simplified.[1] The reason for this is that the three level logic (and, not, or) built into each logic card is not easy to reduce mathematically. The method used is to specify the functions through diagrams. In this way conditional [illegible] may be built up without carrying along the [illegible] of logical manipulations that would be required. The technique used is important [illegible] naming each interior point of [illegible] once the design diagram is completed, an equation file can be written in terms of inputs to each inverter.

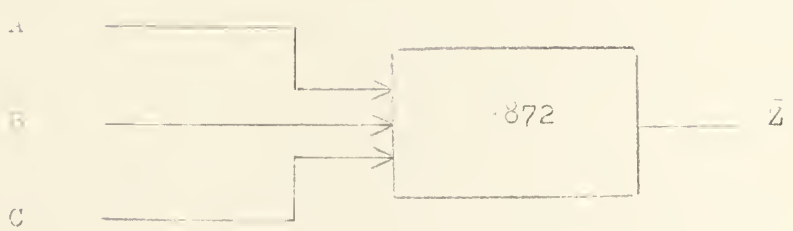
[1] A comparative system which can be simplified mathematically is the "Sheffer stroke" system.



$$Z = A \cdot B \cdot C$$

$$\bar{Z} = \overline{A \cdot B \cdot C} = \bar{A} + \bar{B} + \bar{C}$$

LOGICAL "AND"



$$Z = A + B + C$$

$$\bar{Z} + \overline{A + B + C} = \bar{A} \cdot \bar{B} \cdot \bar{C}$$

LOGICAL "OR"

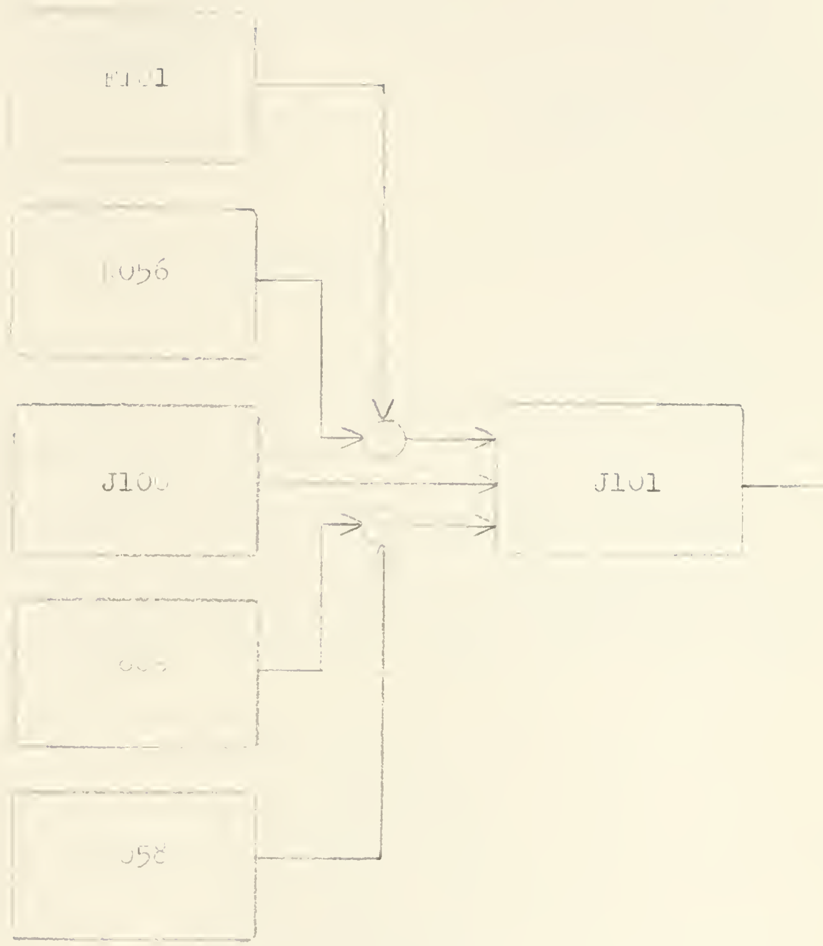
Figure 4-1
Logic Diagrams in Control Data Corporation Notation

This is shown in Figure 4-2. As the equations are written in terms of inputs, no explicit statement of the inversion is needed. When the design diagrams have been completed the individual card types may be assigned based on the number of inputs and outputs. Once the card types have been assigned, the total number of cards needed are uniquely known, and a chassis size may be chosen. In this line of cards there are up to three inverter sections on each card. The chassis layout can then be specified by assigning each card section a place on the chassis. This is done by assigning a row, a column, and a section to each inverter. The assignment is usually a compromise between obtaining the minimum lengths of interconnecting wire and keeping sections of the chassis grouped into areas of logical functions.

The last step in committing a logical design to hardware is the actual assignment and completion of the interconnecting wiring. The wiring constraints are set by the fact that each card socket has only two terminals per pin. This means that multiple AND signals have to be distributed along the wiring 'tree'.[1] (See Figure 4-3). The task of assigning pin connectors in a manner to minimize wire length is very tedious, and the tedium of it tends to cause errors in the production of a wiring tabulation.

The desire to minimize the number of errors induced in the process between the design diagram and the wiring tabulation re-

[1]A "tree" is a graph having only one path between every two nodes.

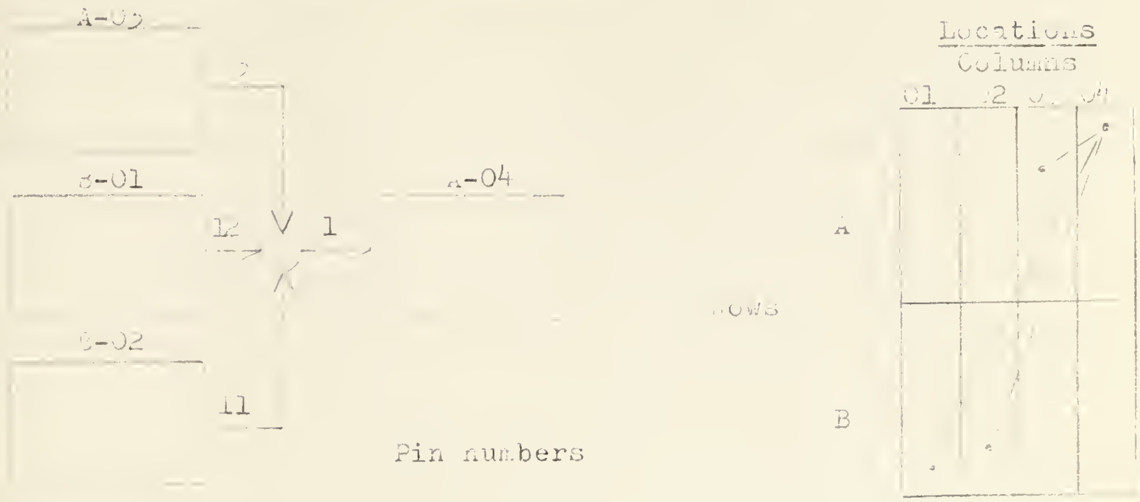


J101 = J100 + B089 K056 + F100 K05

Figure 4-2

Example of an Equation written from a Logic Diagram

In order to wire an "AND" gate of more than two inputs, the following considerations are necessary:



Each connector has only connection terminals for two wires so that the interconnection similar to the depiction in the logic diagram is not possible. The resulting method is to build up a complete wiring "tree" by first accepting the smallest interconnecting wire and then building on this base until all "nodes" have been added to the tree.

Figure 4-3
Constraints on Chassis Wiring

suited for programming, effort being made to mechanize some of the functions on the Control Data Corporation 1[illegible] computer. The computer has been assigned the tasks of formulating and printing out the completed file of equations and the final minimum wire length wire tabulations. Also, the program will assign card types, call attention to illegal equations, and give a tabular total of the number of cards by types required to implement the design. The necessary inputs are a set of "punched cards" which each of which contain the equation for a single logic card section and a location for that logic card. The detailed report on usage of the program and an assembly listing of the program is included as Appendix [illegible] of this thesis. A sample of the input and outputs are shown in Figures 4-[illegible], 4-5, 4-6, and 4-7.

The method for computing the minimum length wiring to connect a group of nodes is based on an algorithm by Loberman and Weinberger./[illegible]1/

This program was used in the production of the minimal wiring data for the [illegible]-5. The total card count for the design is over 1500 cards. There are two separate chassis which made separate program runs necessary. The time required to compute the complete output listing was less than 20 minutes (exclusive of printing the magnetic tape off-line).

```
                   CHASSIS 1    DD 65
A000 = A001 + A002 V205 + A101 N009 + A201 N109          J1 J05A
A001 = A000 J842 + A003 V205 + N108 + GNDE               J1 J06A
A002 = A003 + A001 N800                                  J1 L04A
A003 = A002 + A000 N800 + GNDE + GNDE                    J1 J07A
A010 = A011 + A012 A003 V205 + A111 N009 + A211 N109     J1 J05C
A011 = A010 + A013 A003 V205 + N108 + GNDE               J1 J03A
A012 = A013 + A011 N800                                  J1 K03C
A013 = A012 + A010 N800                                  J1 K03A
A020 = A021 + A022 A013 A003 V205 + A121 N009 + A221 N109  J1 L08A
A021 = A020 + A023 A013 A003 V205 + N108 + GNDE          J1 L07A
A022 = A023 + A021 N802                                  J1 L06A
A023 = A022 + A020 N800                                  J1 L06C
A030 = A031 + A032 V215 + A131 N009 + A231 N109          J1 L08C
A031 = A030 + A033 V215 + N108 + GNDE                    J1 L09A
A032 = A033 + A031 N802                                  J1 L10C
A033 = A032 + A030 N802                                  J1 L10A
A040 = A041 + A042 A033 V215 + A141 N009 + A241 N109     J1 N08A
A041 = A040 + A043 A033 V215 + N108 + GNDE               J1 M08A
A042 = A043 + A040 N804                                  J1 M09A
A043 = A042 + A041 N802                                  J1 M09C
A050 = A051 + A052 V225 + A151 N019 + A251 N119          J1 N08C
A051 = A050 + A053 V215 + N118 + GNDE                    J1 N09A
A052 = A053 + A051 N804                                  J1 N07C
```

Figure 4-4
Sample of Input to Mechanization Program

```
CHASSIS 1    DD 65

A000 = A001 + A002 V205 + A101 N009 + A201 N109
 J1 J05A    24    A003,    A001,

A001 = A000 J842 + A003 V205 + N108 + GNDE
 J1 J06A    14    T011,    H215,    A200,    A100,    A002,    A000,

A002 = A003 + A001 N800
 J1 L04A    22    T012,    T010,    A003,    A000,

A003 = A002 + A000 N800 + GNDE + GNDE
 J1 J07A    14    T013,    A021,    A020,    A011,    A010,    A002,    A001,

A010 = A011 + A012 A003 V205 + A111 N009 + A211 N109
 J1 J05C    24    A013,    A011,

A011 = A010 + A013 A003 V205 + N108 + GNDE
 J1 J03A    14    T013,    T012,    H215,    A210,    A110,    A012,    A010,

A012 = A013 + A011 N800
 J1 K03C    22    T011,    T010,    A013,    A010,

A013 = A012 + A010 N800
 J1 K03A    22    A021,    A020,    A012,    A011,

A020 = A021 + A022 A013 A003 V205 + A121 N009 + A221 N109
 J1 L08A    24    A023,    A021,

A021 = A020 + A023 A013 A003 V205 + N108 + GNDE
 J1 L07A    14    H215,    A220,    A120,    A022,    A020,

A022 = A023 + A021 N802
 J1 L06A    22    T001,    A023,    A020,

A023 = A022 + A020 N800
 J1 L06C    22    T000,    A022,    A021,

A030 = A031 + A032 V215 + A131 N009 + A231 N109
 J1 L08C    24    A033,    A031,

A031 = A030 + A033 V215 + N108 + GNDE
 J1 L09A    14    T002,    H225,    A230,    A130,    A032,    A030,

A032 = A033 + A031 N802
 J1 L10C    22    T003,    A033,    A030,
```

Figure 1. Sample of output of file of equations

U S NAVAL POST GRADUATE SCHOOL   DATA PROCESSING LABORATORY

COMPILATION OF CARD ASSIGNMENTS

CARD TYPE	NUMBER OF CARDS
11	1
12	NONE
13	NONE
14	210
15	1
16	36
31	NONE
32	NONE
33	NONE
21	81
22	204 1/2
23	17
24	29
01	21
61	NONE
62	NONE
S36	3 2/3
S04	NONE

Figure 4-6

Sample of Card Compilation

U S NAVAL POST GRADUATE SCHOOL   DATA PROCESSING LABORATORY

INTER CARD WIRING TABULATION

	ORIGIN	DESTINATION	DESIGNATIONS	WIRE LENGTH
*	J05-01	J06-12	A000 TO A001	3 INCHES
*	L04-06	J09-12	A002 TO V205	6 1/2 INCHES
	J05-02	J09-12	A000 TO V205	3 1/2 INCHES
*	J05-03	I03-12	A000 TO N009	3 INCHES
	I02-12	I03-12	A101 TO N009	1 1/2 INCHES
*	J05-04	H05-06	A000 TO A201	7 INCHES
	H05-06	H12-06	A201 TO N109	4 INCHES
*	J06-01	J842	A001 TO J842	31 1/2 INCHES
	J06-01	J05-06	A001 TO A000	2 INCHES
*	J06-02	J07-12	A001 TO A003	3 INCHES
	J07-12	J09-11	A003 TO V205	2 INCHES
*	J06-03	L01-06	A001 TO N108	8 INCHES
*	J06-04	GNDE	A001 TO GNDE	32 INCHES
*	L04-01	J07-11	A002 TO A003	6 INCHES
*	L04-02	J06-11	A002 TO A001	6 INCHES
	J06-11	J08-12	A001 TO N800	2 INCHES
*	J07-01	L04-05	A003 TO A002	8 INCHES
*	J07-02	J08-11	A003 TO N800	2 1/2 INCHES
	J07-02	J05-05	A003 TO A000	2 INCHES
*	J07-03	GNDE	A003 TO GNDE	32 INCHES

Figure 4-7 Sample of Wiring Tabulation

5. Radar Conversion Unit

The system must perform the two separate functions previously described in Chapter 3, i.e., (a) that of direct display of unprocessed video on a digital raster on a display tube, and (b) that of making available to the computer the digital information on a radar return if it is a possible target.

The requirement of a real time radar display places a restriction on the use of the display for computer generated information. The portion of time between start of sweep and the maximum range to be displayed must generate a signal to lock out any memory references to the display. As a result of this restriction, the system has been designed to include two separate display tubes so that one is always available for computer generated display information. The normal display information in the memory is directed to the designated display tube. The tubes are designated "0" for left and "1" for right for purposes of coding commands. The choice of which tube is to present the display is controlled by the use of the tube designator bit in the coding structure which will be discussed later. This "tube bit" controls the intensity grid of the designated tube by enabling the "unblank circuitry" to turn on the electron beam. Also, it sets the condition which [illegible] the display deflection signals to the designated tube. When radar video information is desired, the range switch is placed to the appropriate range. The receipt of a "main bang" from the radar sets a flip-flop whose output is used to remove control of the [illegible] the internally generated display information (see Figure [illegible]). The

"set" output of the flip-flop "enables" the X and Y digital radar counters to input to the position registers of the digital to analog converters. The "set" output also "disables" the output of the computer generated display information, even though tube "O" may be designated to display some information while in the radar mode. When the designated maximum range has been reached, a signal is generated which "resets" the flip-flop. Thus, the internal display information can now be displayed on tube "O" until the next "main bang".

The range switch settings are shown in Figure 5-1 along with the time required by the radar to display each beam. This is based on the propagation rate of radar signals being 12.35 microseconds per range mile. The radar characteristics of the unclassified radars to be used with the system are shown in Figure 5-2. The remainder of the table in Figure 5-1 is a listing of the proportion of time remaining for inserting computer generated displays to the total amount of time possible. This information should be used when writing system programs to superimpose target information over a radar display. For example, if using the SPS-8 with the pulse repetition frequency set to [illegible] cycles per second and the range switch set to 64 miles, the availability of tube "O" to the generated display is [illegible].4% of the time. This indicates that the information should be written into the memory at two places to insure that it will be displayed. This technique of time sharing limits the amount of information that can be superimposed on the longer ranges. The SPS-2[illegible] places a slightly more stringent set of re-

[illegible] Switch Setting in [illegible]	Radar Display Time Requirements in Micro-seconds	Ratio of Time Available for Display			
		S P S - 8		[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	198	[illegible]	[illegible]	[illegible]	[illegible]
32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	.508	[illegible]	[illegible]	[illegible]
128	[illegible]		[illegible]	[illegible]	[illegible]
256	[illegible]			[illegible]	[illegible]

Figure 5-1
Comparison Table of [illegible]

	[illegible]-6	[illegible]-12	[illegible]
Horizontal Beam Width (in degrees)	.5	3	.5
Horizontal Rotation Rate of Antenna (in revolutions per minute)	5 to 1	[illegible] to 1[illegible]	1 to 10
Vertical Beam Width (in degrees)	[illegible]0	[illegible]	[illegible].1
Azimuth Information Available	1:1 speed synchro	1:1 speed synchro	1:1 speed & [illegible]:1 speed synchro
Peak Power (in kilowatts)	50[illegible]	500	[illegible]
Pulse Width (in microseconds)	4	4	[illegible]
Pulse Repetition Frequency (in cycles per second)	150	[illegible]00	1[illegible] or [illegible]
Expected Range (in miles for 1 square meter target)	[illegible]	[illegible]2	[illegible]

Figure [illegible]-2
Characteristics of Radars to be Used in the System

quirements on the display for time sharing than any of the unclassified radars.

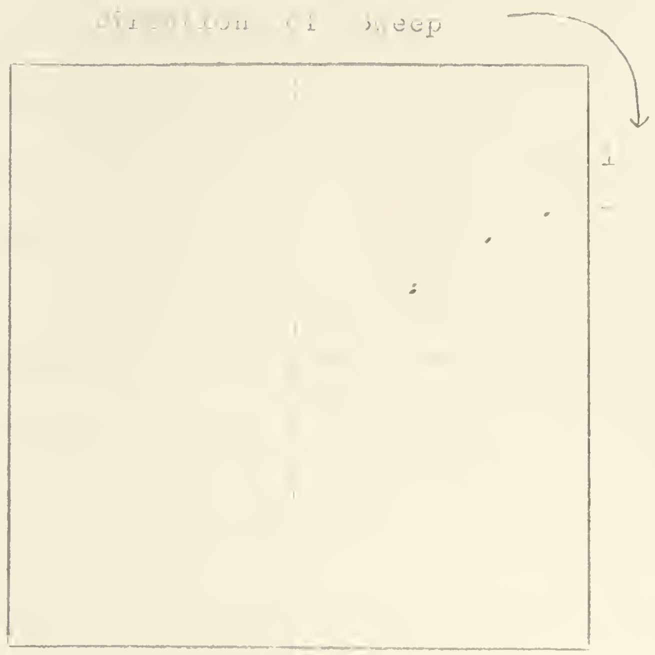
The method of generating the radar sweep requires accurate azimuth information in the form of a shaft position from the radar. This shaft motion drives a digital shaft position encoder whose outputs are sine ϕ and cosine ϕ. The outputs have an accuracy of ten magnitude bits plus a sign bit. These quadrature values are then "multiplied" by a series of range pulses in such a manner that counters being driven by the multipliers hold the results $R(\text{sine } \phi) = Y$, and $R(\text{cosine } \phi) = X$. When the range counter reaches its maximum value as determined by the range switch, the range counter is cleared, and the X and Y counters are then disconnected from the digital analog converters by the "enable radar" flip-flop previously described.

This technique then describes a radar display raster of the form shown in Figure 5-3. There are 2,048 separate "bins" in X and in Y corresponding to the 11 bits. This gives a possible accuracy of $\pm$ 1/4 nautical mile on the 250 mile range with possible accuracies increasing to $\pm$ 7.9 yards on the four mile range. The actual accuracy of the video display without a video processor incorporated to use only the centroid of the radar return is mainly limited by the pulse width of the radar used. The pulse widths range from one to four microseconds (see Figure 5-2) with a resulting possible error of approximately $\pm$ 1/12 mile to $\pm$ 1/3 mile.

The heart of this system is the range counter and the oscillator driving the counter. The clock frequency required to obtain

the accuracies needed is 20.72 μsec. The range switch then enables different bit positions of the counter to trigger the rate multiplier which results in full scale deflections for the chosen range. The radar section of the logic is the unit that determined the need for the new series of fast cards discussed in Chapter 4. The switching times of these logic cards were required to be much faster to reduce spikes in the radar video raster caused by the carry pulse in the counters when the most significant bit changes. (See Figure 5-[illegible]) These spikes (or "blivets") should be reduced in width enough to be insignificant by the fast cards.

The requirement of 11 bits of accuracy for the azimuth information requires accuracy to 0.176 degrees. The azimuth information available from the radars is in the form of 60 cycles per second synchro signals. The SPS-8 and SPS-26 have two-speed synchro systems which have an accuracy well within the 11 bits specified by the encoder. The SPS-6 and SPS-12 have only a one-speed synchro system which could have a maximum accuracy of about 0.3 degrees from the components. It is evident then that the available accuracy of bearing information is not quite precise enough for the system requirements. One other problem in this system is that the torque and inertia loads of the shaft position encoder require a high gain servo-system to drive the encoder. In order to furnish the maximum accuracy at suitable power levels to the encoder for each of the radar inputs, it was necessary to convert the individual radar synchro outputs to a single speed, high accuracy synchro output from the radar switch panel. The converter to be used for



The waveforms of successive sweeps 1 and 2 in the above raster are shown below.

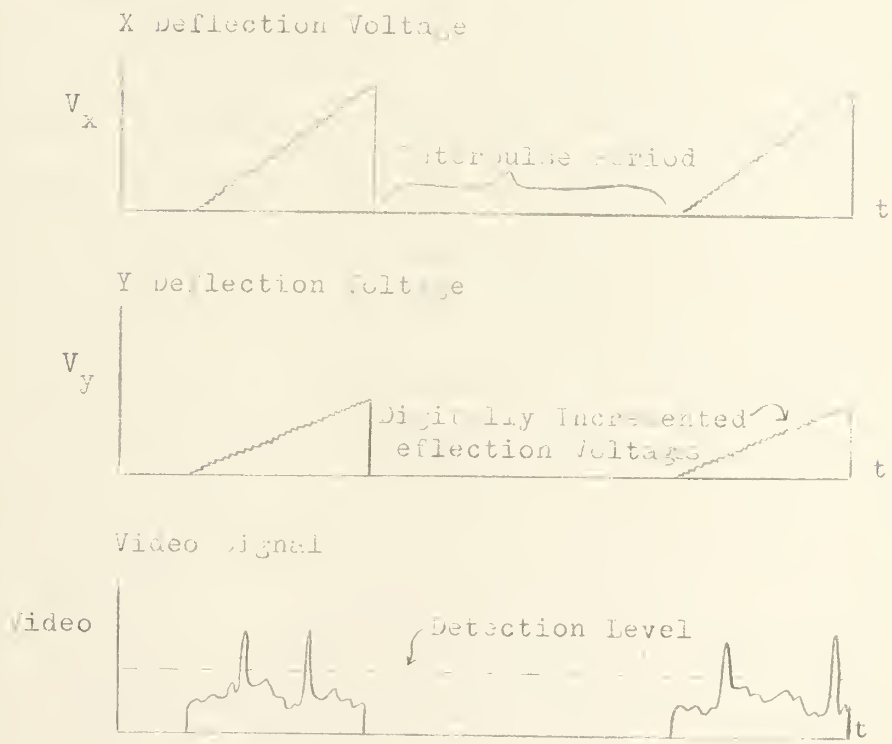
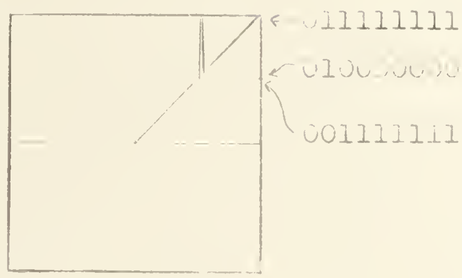


Figure 5-5 Example of the Digital Raster Produced by the Radar Scan

The condition exists when a digital increase of one increment in the lowest order bit position causes a carry bit in the higher order bit positions. For example: for a change of the Y counter from 001111111 to 010000000, two possibilities may occur if the circuits concerned have a large difference in rise times.

1. The carry bits may be too fast resulting in the value of 011111111 for an instant.



2. The carry bits may be too slow resulting in the value of 000000000 for an instant.

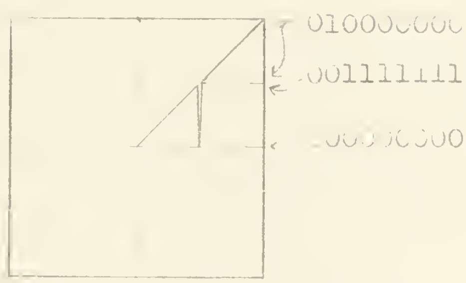


Figure 5-4

Formation of "blivets"

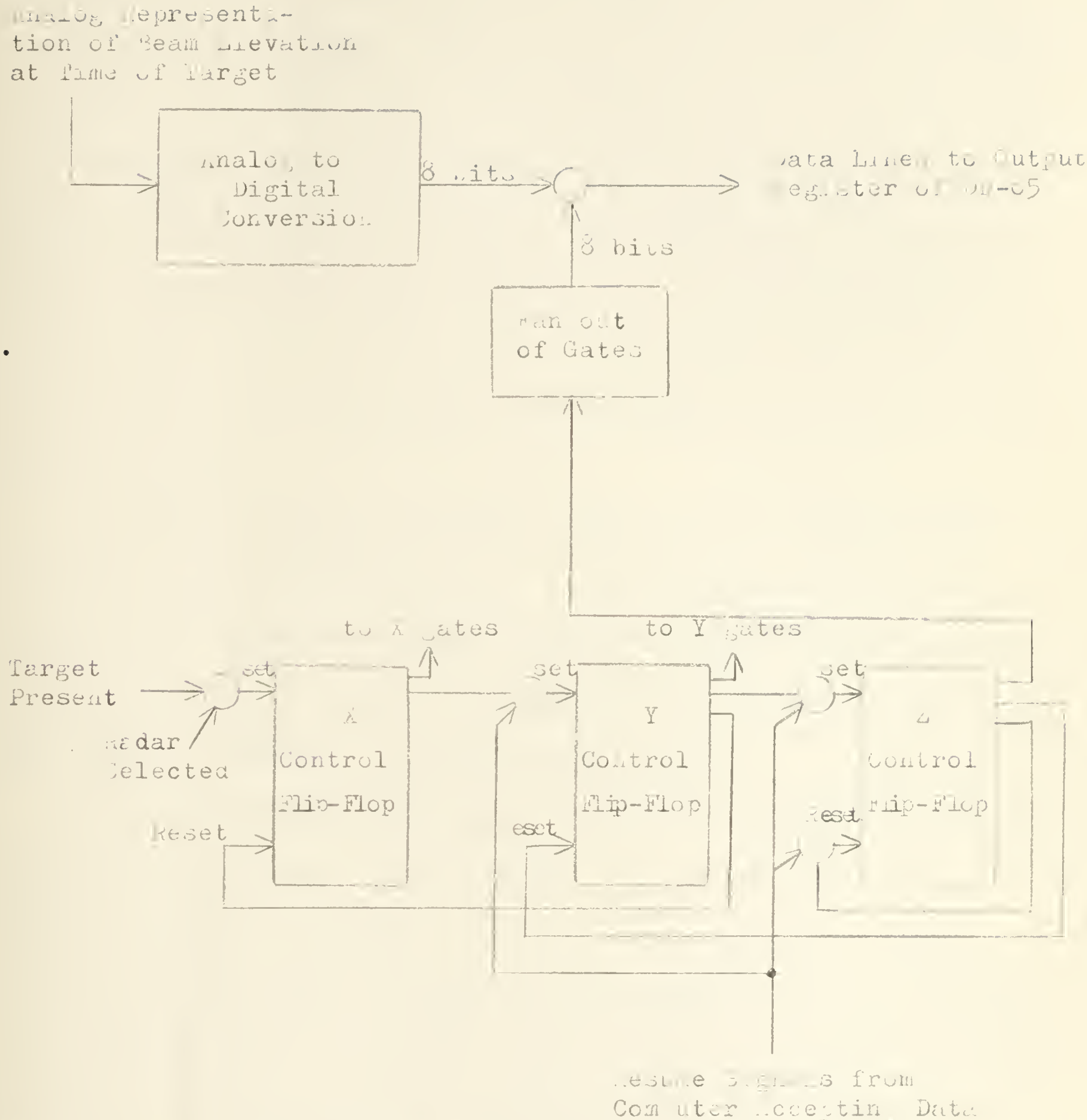
this is a "synchro amplifier". The unit is a standard Navy Supply servo system which accepts one or two speed synchro information and furnishes an accurate one speed synchro output. The output is specified to be a 400 cycle synchro signal for the long cable run from the Radar Laboratory to the Digital Control and Automation Laboratory. A commercial high gain servo system is to be purchased for driving the encoder unit in the DD-65.

The remaining requirement that the digital radar information be made available to the computer has been implemented by gating the 11 bits of X and 11 bits of Y to storage registers upon receipt of a signal signifying the presence of a possible target. This signal will be generated from raw video by an automatic detector which is designed to trigger when certain conditions are met, such as amplitude, slope of signal envelope, or combinations of time and amplitude. The study of optimum auto-detection units is to be one of the primary uses of this system. The detection units are to be fabricated on standard computer cards and locations for these circuits have been left in the operator's console of the DD-65. One type of detector has been designed and build by D. R. Briggs. It is a threshold detector with a voltage variable false alarm rate. This unit will be used on initial tests and is documented in a separate report /21/.

In the system design it was assumed that either the 160 or 1604 could be called on to process the radar data; so the X and Y registers were designed to be callable separately by the computers instead of packing them into a 22-bit word. This allows the 160

with its 1[illegible]-bit word structure to handle the processing job without excessive shifting of bits. The request by the computer for radar information sets a step counter which will sequence the X and then the Y information in a two-word group. The computer program must be tailored to this grouping by using a standard block input coding.

Provision has been left for extending the step counter to a three-word radar sequence. This was done to allow a third word, containing some measure of elevation angle or height information, to be sent to the computer for processing when using the SPS-26 or SPS-6. The output register of the DD-55 has eight bits set aside for this purpose. The implementation of this will entail an analog to digital conversion of the raw data into eight bits of digital information and provide a gate controlled by the third count of the step counter to enable the lines to the output register (see figure 5-5).



Present logic includes only the X and Y control flip-flops.

NOTE: Set side of flip-flop is upper side; reset side of flip-flop is lower side.

Figure 5-9
Necessary Logic for Addition of Height Information

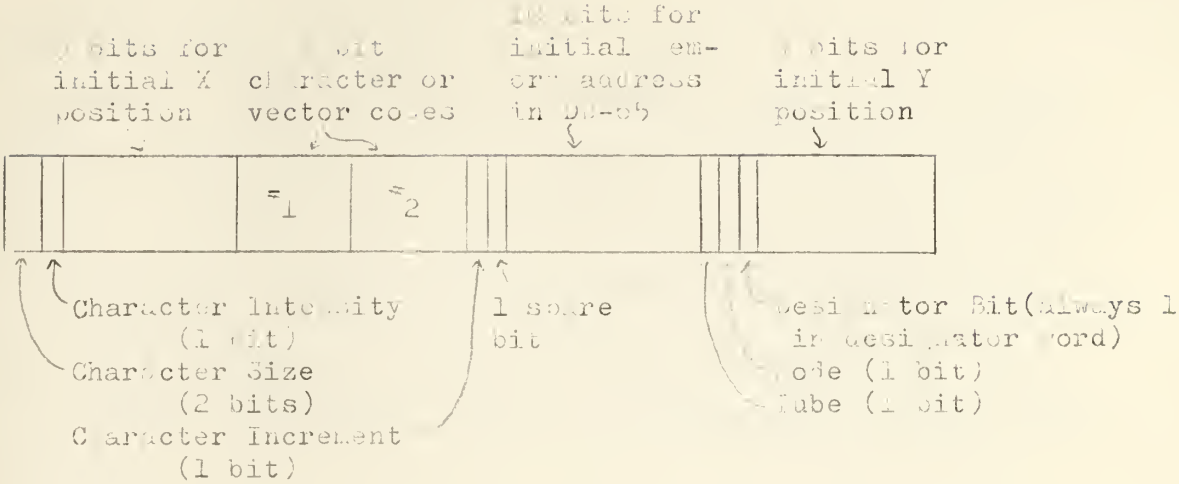
b. Design of Character and Vector Generators

The display of the actual characters and vectors is performed by cycling through the self-contained memory in the SD-65. This memory size is 1024 x 24. Therefore, in order to fill the memory with information, 512 words of 48 bits each would be required from the Control Data Corporation 1604 or 2,048 words of 12 bits each would be required from the Control Data Corporation 160. Any updating of information from the computers to the SD-65 breaks the display cycle, but saves the address of the next display word, and continues from the break address after the new information is read into the memory.

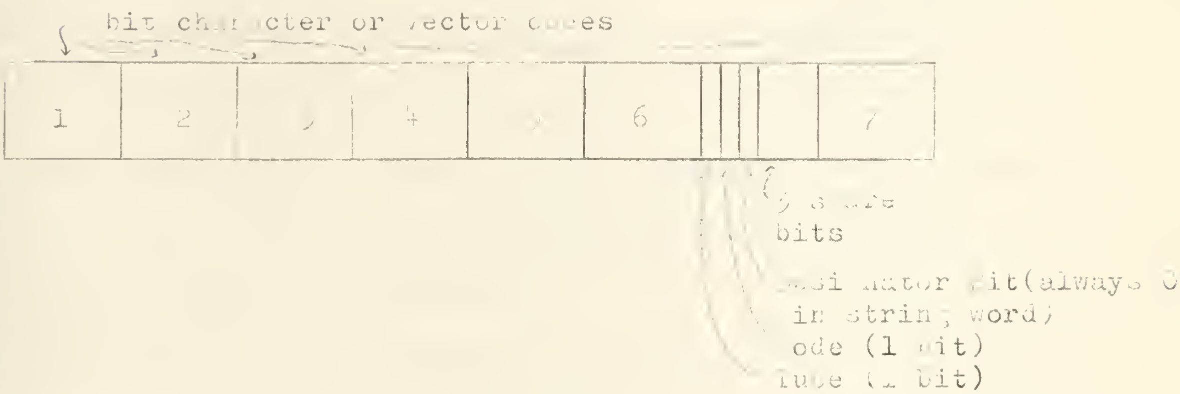
The basic length of the words needed by the decoding logic is 48 bits. This requirement is dictated by the fact that the number of bits needed for control information, position, and address are more than the 24 bits of the memory word. This then limits the total possible number of display words to 512.

As was mentioned previously, the formation of the characters or vectors are grouped into "strings". The first word of each string is called a "designator word". (see Figure 5-1) This furnishes the control information to the decoding logic to prepare for displaying the information. Two characters or vectors can also be packed into the "designator word" to provide fast updating of a moving symbol. All following words up to the next "designator word" are considered to be string words. They can have up to seven characters or vectors packed into each word. The reason for using only seven of the eight possible symbols is the need to be able to

DESIGNATOR WORD (1-1 word or 1-16 words)



SUBSEQUENT STRING WORDS



CONTROL CODES:

Mode: 0 - character (enables logic to decode the character information codes)

1 - Vector mode (enables logic to decode the vector information)

Tube: 0 - Display the stored information on left tube

1 - Display the stored information on right tube

X and Y positional information is formed by an eight-bit "absolute" magnitude code with a sign bit added to indicate direction from the center of the tube (0 sign bit is positive and 1 is negative). Initial memory address of DD-65 must be specified for each string by a 10-bit address code. The storage of consecutive words is incremented within the logic.

Figure 6-1 Programming Information for String Words

uniquely recognize the designator bit "D". Thus, the "D" bit must remain "0" in all string words.

In order to make corrections or update any part of a string, the whole corrected string must be read into the display memory. This is due to the incremental mechanization of the address counter. Only the designator word contains an address reference for the memory. Once a string of display words has been set up to read into the memory, the address counter is incremented as each 24 bits is accepted.

The designator word also contains the initial positioning information for the string. The initial position of the string is specified by nine bits of X and nine bits of Y. This allows a position to be selected to within 1/512 of the usable scope face. The usable portion of a 12-inch diameter tube is a square raster of about 8.5 inches. This allows the position of any symbols to be designated to within 0.0165 inches.

The choice of tube to display the information and the mode (i.e., choice of whether the information is a character or vector string) must be repeated in each word of the string. The appropriate coding for these are shown in Figure 6-1.

The vector mode and the character incrementing portion of the character mode use the same logical packages. These are a pair of nine bit position counters. The X and Y position counters are initially set to the position specified in the designator word for a string. The outputs of these counters drive the position registers of the digital-analog converters for the display tubes (see Fig-

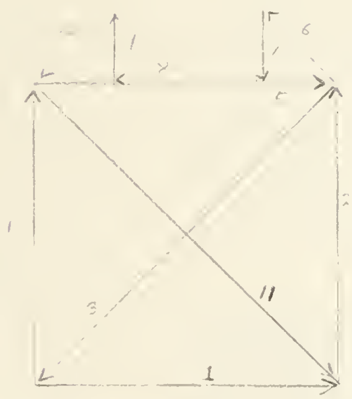
ure 6-1). The counters are designed so that the contents may be counted up or down or not incremented depending on the control signals generated in the decoding logic. Thus, the amount and direction of beam movement is determined by the individual mode decoding circuits.

The vector mode requires only initial position information from the designator word. The formation of a line is started by unblanking the beam and then moving it a direction and distance as specified by a six-bit vector code. The beam is then "blanked" while the next six-bit vector code is brought into the decode logic. The sequence is then repeated until the next designator word is encountered. This technique produces a line by starting each new segment from the end point of the last (see Figure 6-2). The blank words between the end of any information and the next designator word causes no problem as the "0" code in either the vector or character mode does not unblank the beam even though the position counters may be incrementing.

The vector decode logic separates the six-bit code into a three-bit direction code, a two-bit size code, and an "unblank" bit. The direction code allows for eight possible directions which corresponds to 45° increments in direction. The size code allows for four possible segment lengths. The unblank bit can be used to form dashed lines by allowing the beam to be blanked while still following a prescribed vector path. The vector codes are shown in Figure 6-3. The direction code determines the operation of the X and Y position counters, i.e., whether to count up, count down or

In order to depict the location of an infantry battalion on a military map, the following symbol is used:

To include this symbol on a map generated by the [illegible], the following trace could be generated:



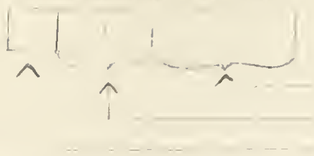
The sequence of necessary vector codes (see Figure [illegible]) to form the above symbol is:

(1) 110000
(2) 110010
(3) [illegible]
(4) 110010
(5) 11000[illegible]
(6) 000011
(7) 1[illegible]0
(8) [illegible]
(9) 100[illegible]
(10) [illegible]0101
(11) 11[illegible]

Note: The starting point location must be given in the designator word.

Figure 6-2 Example of the Trace Produced by Vectors

Vector format (6 bits per vector)



Intensity Information

Code	Interpretation
0	No brightening of the beam
1	Normal intensity

Size Information

Code	Interpretation
00	X and/or Y coordinate deflection is 1/128 of full scale deflection
01	X and/or Y coordinate deflection is 1/64 of full scale deflection
10	X and/or Y coordinate deflection is 1/32 of full scale deflection
11	X and/or Y coordinate deflection is 1/8 of full scall deflection

Direction Information

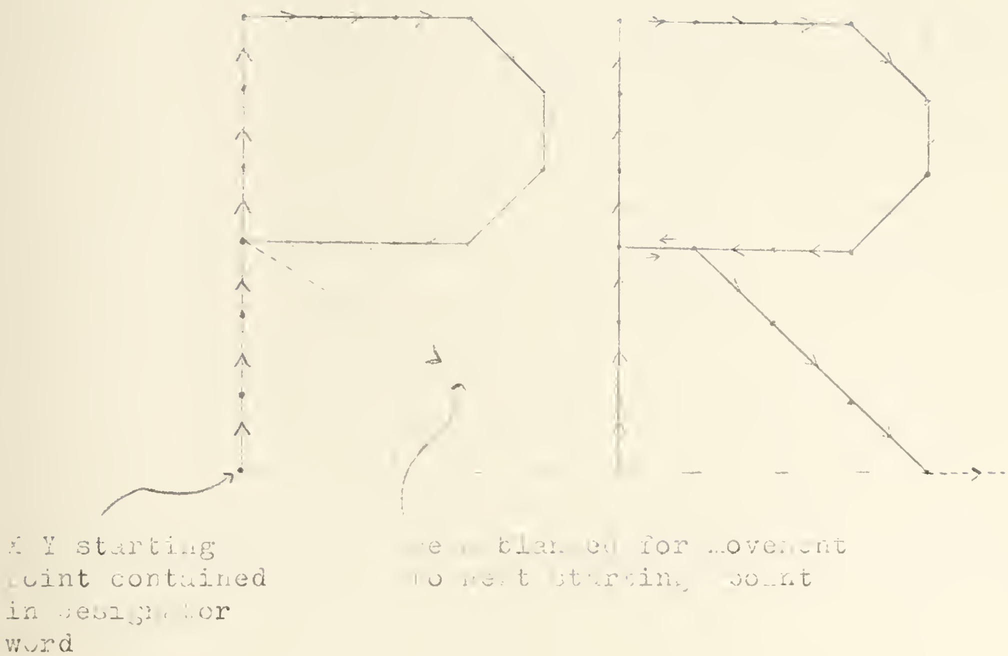
Code	Interpretation
000	Vector is drawn at an angle of 0° from starting point
001	Vector is drawn at an angle of 45° from starting point
010	Vector is drawn at an angle of 90° from starting point
011	Vector is drawn at an angle of 135° from starting point
100	Vector is drawn at an angle of 180° from starting point
101	Vector is drawn at an angle of -135° from starting point
110	Vector is drawn at an angle of -90° from starting point
111	Vector is drawn at an angle of -45° from starting point

Figure 6-3
Programming Information for Coding Vectors

not count. The length code determines when to stop incrementing the counters. The incrementing rate is 0.4 microseconds per pulse, and the number of counts must increase in proportion with the line length. The longest line length was included for the purpose of economical drawing of ordinates. One line, the length of the digital raster, can be packed into a string of two words. It is felt that the smallest increment will allow special symbols to be made up from coded vector strings without being incompatible with the normal character sizes.

The character decode logic is considered to be proprietary information by Data Display, Incorporated. The general technique is one of micro-positioning the beam in relation to a reference X, Y position on a 5 x 7 matrix. The logic is entirely designed from the basic inverter logic cards. The characters are formed by moving the beam and turning it on and off under a clock control whose pulses occur every 0.2 microseconds. The character rate is determined by the number of increments needed to trace the most complex character. For the symbol selection of the DD-65 the number of increments required is 33 pulses. This sets the time for display of one character at 6.6 microseconds. This time includes the incrementing of the reference position to the next character location (see Figure 6-4).

In addition to the initializing information required in the designator word by both the vector and character modes, the character mode requires some additional information on size and incrementing. A convenience intensity control bit is included to



Formation is on a 5 x 7 matrix with spacing generated by the matrix size being slightly smaller than the incrementing deflection.

NOTE: The incrementing information is contained in the designator word.

Figure 3-4
Example of the Trace Produced by Characters

allow [illegible] normal [illegible] characters for [illegible] of superimposing data over a background or radar display. The format is shown in Figure [illegible]-1. The bit pattern of these information bits sets flip-flops which control these functions throughout the current string. The size selection is limited to only three out of [illegible] possible four as no need is seen for the [illegible] characters. The character size has a direct relation with the position increment length. As the vectors and characters use the same position counters, the character sizes were adopted to the increment lengths designated for vector lengths. The various codes for character control are shown in Figure [illegible]. The normal character sizes are the 32 or 64 per display width. The small size was incorporated to allow for possible future photography techniques which could allow large quantities of printed text to be [illegible] recorded for later projection. The direction of incrementing characters within a string is normally to the left to right as in a printed page, but for possible labeling of graphs or [illegible], a down increment has been included. This [illegible] easily incorporated as the [illegible] can be [illegible] into the minus side of the [illegible] counter for [illegible] complexity than required for [illegible] only into the plus side of the X counter.

Size Information (2 bits)

Code	Interpretation
00	Character size is 1/128 of full scale deflection
01	Character size is 1/64 of full scale deflection
10	Character size is 1/32 of full scale deflection

Incrementing Information (1 bit)

Code	Interpretation
0	Successive characters are incremented to the right
1	Successive characters are incremented vertically downward

Intensity Information (1 bit)

Code	Interpretation
0	Normal intensity
1	Brighter than normal intensity

NOTE: The usage of these character control codes is shown in Figure 5-1.

Figure 5-5
Character Control Codes

7. Design of the Input, Output and Control Functions

In order to commit the requirements of Chapter [illegible] to hardware, a suitable set of rules in the form of logical circuitry must be designed to allow for the establishment of communications between the various units of the system, and the collection and transfer of data between these units.

The establishment of communications with the computers is accomplished within the standard structure of sense and select commands of the Control Data Corporation 160 and 1604. These commands and the control signals have been documented in the company manuals /17, 18/ and have been included as Appendix 2 to this thesis. All reference to command structures will be made in "octal" notation instead of the actual binary notation. The requirement that the computers can be selectively locked out of the system places an additional restriction on the decode functions. It was decided that in the individual computer operation modes (i.e., 160 only or 1604 only), the select codes for the other computer would be uniquely locked out. In the combined operation mode ("both"), the restrictions were lifted, and the computers can cross select to control the flow of information. For example, it is possible for the 160 to select an interrupt condition for the 1604 in this mode. The only arbitrary decision concerns the flow of manual input (i.e., keyboards, track ball and range switch). In the "both" mode all manual input selects are gated so that the data is input to the 1604.

The request for information or action by a computer is indicated by a 12-bit external function code being transmitted to all

peripheral equipment along with any control signals over their separate lines. From a study of all codes assigned to actual or proposed peripheral equipment for the computers, it was found that the 7XXX series of codes was not designated. This 7XXX series was chosen as the unique code series of the DD-65.

In order to continue further into the design of the control structure of the DD-65, it next became necessary to precisely define the various inputs and outputs and their inter-relationships.

The structure of the display words to be transferred from the computers to the DD-65 has been described in Chapter 6. These are the only data channel inputs to the system from the computers. The transfer of the "strings" of display information is to be by normal computer output blocks. The DD-65 must, then, have the provision for recognizing commands from the computers, to select this transfer, and to set up a "ready - resume" system of signals to control the input of the blocks of information. These two transfer channels have no restrictions set on them by other data modes of the system, but they should be mutually exclusive.

The digitized radar information is a sequence of words from the radar channel to one of three possible terminal equipments, i.e., the 1604, the 160 or the auxiliary channel. The sequence is controlled by a counter which successively gates in the 11 bits of X and the 11 bits of Y, and has provision for extending this to gate in eight bits of height information. These eight bits of elevation allow an angular resolution of about 1/4 degree. This sequence is triggered by an externally produced target pulse which

is manufactured from the view of the detection circuit. This input entails two levels of selection to be made by the select code used. These are: (a) The choice of one out of three possible terminations for the information and (b) the selection of accepting the radar information exclusive of all other inputs to the DD-65 except from the computers.

The group of manual inputs from the operator's console can only be directed to the computer assigned by the mode switch (as described in this section). This places the requirement for only a single input selection on the select code. The selection is to be exclusive of all other normal input selects.

There is one other unique input necessary from the DD-65 to the Control Data Corporation 160. This is the response to a "status request". This response should be selectable to the exclusion of all other inputs when the program on the 160 is checking for the occurrence of conditions at the DD-65. The response is coded into a one out of twelve response. In this way, if more than one recognizable condition has occurred, the response will include them, and it is up to the 160 program to check for the conditions. The "status response" selection is disabled when in the "1604 only" mode. Note that the 1604 operates the sensing of conditions of the peripheral equipment in a different manner. It uses a separate control signal to denote that the condition has been met.

To expand on the manual inputs, the following separate pieces of information are generated:

a. X track ball — 9 bits

b. Y track ball [illegible] bits

c. Overlay [illegible] bits

d. Range switch 3 bits

e. Symbol keyboard (number 1) [illegible] bits

f. Control keyboard (number 2) [illegible] bits

The X and Y track ball information has been made separately selectable to keep the DD-65 output register to less than 12 bits so that the same output register and usage rules may be used by both the 160 and 1604. The overlay and the control keyboard have been combined into a nine-bit output, as the method of interpreting the commands of the control keyboard is dependent on the overlay which should control the program package. The range switch and the symbol keyboard are treated independently.

The use of light feedbacks to the console operator (in conjunction with the control keyboard) dictated the need for additional select code requirements. These select codes are used to turn on or off any of the lights associated with the control keyboard. There is no restriction on the use of these selects as they have no inter-action with the inputs or outputs.

One other mode of operation to be incorporated is that of using the interrupt feature available on the Control Data Corporation 1604. These selections need not be unique or exclusive as the portion of the program entered when an interrupt occurs can be made to sense which of the selected interrupts has occurred.

A general diagram of the control function circuits is shown in Figure 7-1. A more detailed breakdown is given in Figure 7-2.

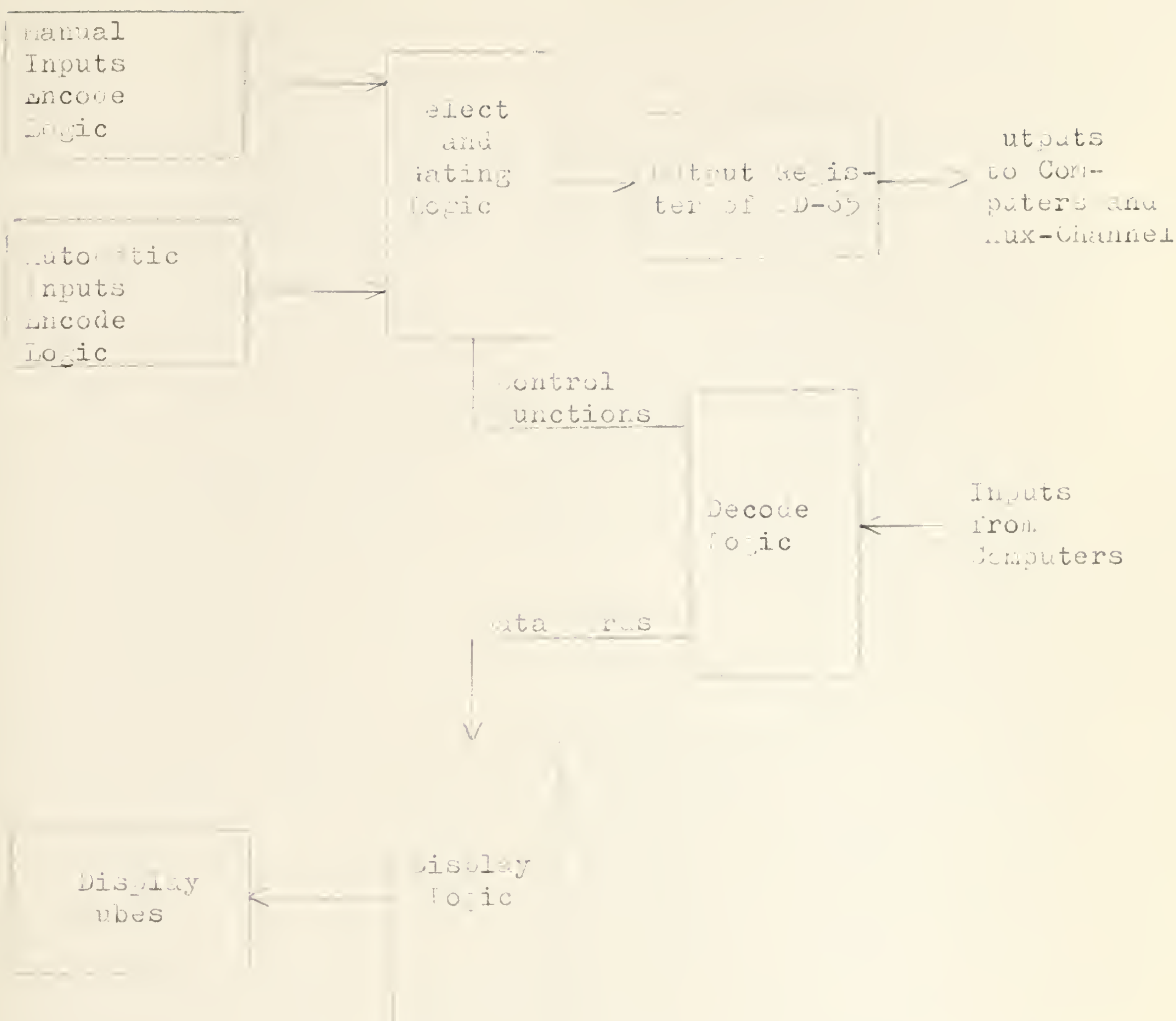


Figure 7-1
General Block Diagram of Control Functions

[illegible] to precisely define the necessary commands. The [illegible] a maximum of [illegible]4 possible [illegible]. This is specified by the allowed six bits in the keyboard code. In order to determine the necessary number of symbols needed for keyboard number one (the symbol keyboard), a comparison was made of the symbol sets required for various programming languages. The comparison included the assembly programs [illegible]-2 [illegible]/ and [illegible] /[illegible]/, the business oriented compiler COBOL /24/, and the algebraic compilers [illegible] /2[illegible]/, [illegible] /26/, and JOVIAL /27/. In addition to the symbol set, it was also necessary to include a certain few editing keys. These are "carriage return", "tab", and "space". The choice of coding for the symbols was made using the criterion that standardization of the code would be desirable. The coding that evolved is an expansion of the basic "Binary Coded Decimal" (BCD) which is standard in most input and output equipments not having a provision for upper and lower case. The code "[illegible]" was not assigned an input symbol, but the key was included on the keyboard so it can act as an alternate space code. This allowed 6[illegible] symbols to be assigned to the remaining codes. The final assignment is shown in Figure 7-2. The physical layout of the keyboard was planned to separate the two major functions of its use. A standard typewriter keyboard and a tabular type numeric keyboard were formed by making the key covers of a different color than the special keys around them. This should allow easier identification of these areas of the keyboard for more efficient usage. The 64-key keyboard was bought as a com-

Symbol	Octal Code	Symbol	Octal Code	Symbol	Octal Code
Ø	1[illegible]	O	4[illegible]	.	73
1	01	P	47	↑	55
2	02	[illegible]	50	,	[illegible]
3	03	R	51	→	35
4	04	[illegible]	22	<	72
5	05	T	23	≥	37
6	06	U	24	≠	14
7	07	V	25	==	13
8	10	W	26	/	21
9	11	X	27	&	[illegible]
A	61	Y	30	+	[illegible]
B	62	Z	31	-	4[illegible]
C	63	CR	7[illegible]	▼	1[illegible]
D	64	Tab	[illegible]	[illegible]	[illegible]
E	65	Space	20	Space	[illegible]
F	66	}	52	∧	57
G	67	{	75		
H	70	[	17		
I	71	]	32		
J	41	[illegible]	34		
K	42	)	74		
L	43	:	15		
M	44	//	53		
N	45	;	77		

Figure 7-2 Symbol Character Codes

plete package. Additional logic was incorporated to make the unit compatible with the "ready - resume" signals of this system. The keyboard layout is shown in Figure 5-5.

The control keyboard (keyboard number two) is a collection of function designators. The proposed usage for them is for calling routines and subroutines for aid in console usage. This keyboard is also closely associated with the overlay and the light feedback features. There are three groupings of switches in this control keyboard (see Figure 5-5). The first group is a 20-switch matrix which is used in conjunction with the overlays. The functions performed by each switch are engraved on the plastic overlay panel which fits around the switches. The computer can illuminate selectively any switch or switches under program control to present a "guided" choice to the operator for his actions. The eight overlays available give a choice of system programs callable from a single library tape. The second group is a ten-switch unit which is also under computer control for light feedback. These are not associated with changeable overlays and are intended to perform functions which are common to all overlays. For instance, one of these keys could be labeled "display track ball symbol on left tube". The last group is a diamond of four switches which are intended to be used in editing symbols. They can be used to activate routines to move a marker over the face of the displays. This marker can be used to indicate the position for writing or erasing the next character. The movement commanded by these switches is intended to be incremental in nature as opposed to the "continuous"

nature of the two c ll. These r keys re not associated with the computer controlled li ht feedback feature.

The coding f keyboard number two is made up from a diode matrix which was designed to use the minimum number of diodes. The coding of these keys is shown in Figure 7- . The depression of a key in keyboard two sets up a ready condition which is held until the computer samples the lines and releases the register. The overlay code is transmitted along with the control keyboard code when the input from keyboard number two is sampled. The overlay code is generated by the presence or absence of a contact post in the three bit positions of each overlay panel. This allows for changing the overlay code with a change of the overlay, and hence, to be able to change the labels associated with each of the 20 switches in the matrix.

The X and Y trackball generators are nine-bit shaft position encoders whose outputs are in "Gray Code" /20/. The outputs are converted to binary code for use in the computer. This coordinate information is always available and need only be selected by the computer to sample the value.

The radar display range switch is an eight-position switch. There are seven selectable ranges and an off position. The codes are shown in Figure 7-4. The switch has the dual function of controlling the radar video presentation and providing the computer with a measure of range correlation for making computations on target position. The entire operator's console is shown in Figure 8-5.

SWITCH POSITION	OCTAL CODE	SWITCH POSITION	OCTAL CODE	SWITCH POSITION	OCTAL CODE
1-A	01	4-A	31	8-1	61
1-B	02	4-B	32	8-2	62
1-C	03	4-C	33	8-3	63
1-D	04	4-D	34	8-4	64
1-E	05	4-E	35		
2-A	11	5-A	41		
2-B	12	5-B	42		
2-C	13	5-C	43		
2-D	14	5-D	44		
2-E	15	5-E	45		
3-A	21	6-A	51		
3-B	22	6-B	52		
3-C	23	6-C	53		
3-D	24	6-D	54		
3-E	25	6-E	55		

Keyboard [illegible] - Function Switch Designation

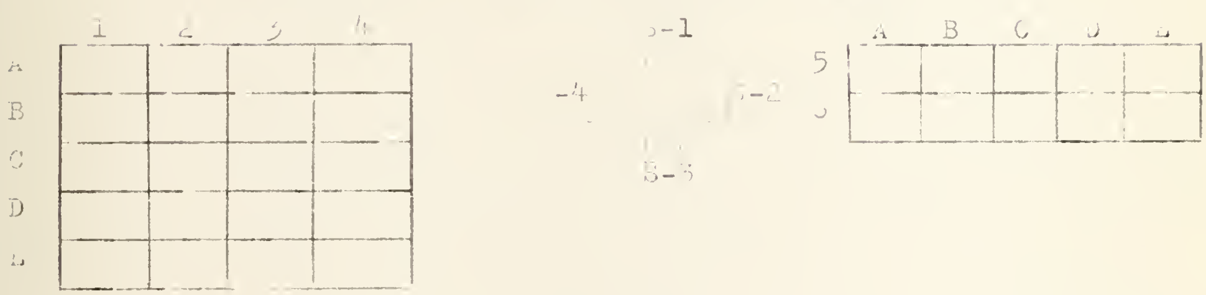


Figure 7-5
Function Switch Codes

SWITCH POSITION	OCTAL CODE
Off	0
4 miles	1
8 miles	2
16 miles	3
32 miles	4
64 miles	5
128 miles	6
256 miles	7

Figure 7-4
Range Switch Codes

Now that all inputs and outputs are defined, it is possible to assign select and sense codes, and design the logic. Two editing functions were added to the sense and interrupt functions. These were the keys 'carriage return' and "tab" of keyboard one. These were included as special cases of keyboard one for the possibility of processing a word or a group of words on a functional command instead of processing single characters. The sense codes are listed in Figure 7-5. The select codes are listed in Figures 7-6 and 7-7.

All the function codes are in the 7XXX series. The primary decode is done by checking for the coincidence of a 7XXX and one of the external function signals from the computers. In the "both" mode of operation a time shared check is made of the external function lines from the 160 and 1604. The checking rate is rapid enough to return to sample each computer bit in the eight microseconds that the function pulse is present. Once the initial 7XXX is recognized, a pulse is formed which samples the lower nine bits of the code and sets the selected flip-flop (or in the case of a sense code for the 1604, allows an output pulse to be formed conditioned on the sense).

The ability to clear all the select flip-flops has been incorporated using the external clear lines of the computer in control (as selected by the mode switch). In addition to these possibilities, the "clear/start" control for the DD-[illegible]5 memory will clear all select flip-flops. The overall diagram of the control logic is shown in Figure 6-2.

Sense Condition	1604 Sense Command Codes	160 Sense Response Codes
Keyboard no. 2 hit	7102	xxx1
Keyboard no. 1 hit	7104	xxx2
Carriage Return hit	7110	xxx4
Tab hit	7120	xx1x
Radar target present	7140	xx2x
Keyboard no. 2 not hit	7103	
Keyboard no. 1 not hit	7105	
Carriage Return not hit	7111	
Tab not hit	7121	
No radar target	71[illegible]1	
Keyboard no. 1 selected	[illegible]	xx4x
Radar to [illegible] selected	70[illegible]1	x1xx
Radar to 1604 selected	[illegible]02	x2xx
Radar to 160 selected	7[illegible]	[illegible]xx
DD-65 from 1604 selected	7[illegible]10	1xxx
DD-65 from 160 selected	7020	2xxx
Keyboard no. 2 selected	7040	4xxx

Figure 7-5
Sense Function Codes

[illegible]	[illegible]	[illegible]	[illegible]
Select Track Ball X	7102	7102	[illegible]
Select Track Ball Y	7104	7104	[illegible] YYYYYY[illegible]
Select Range Switch	7110	7110	[illegible]
Select Keyboard 2 plus Overlay	7120	7120	000VVV[illegible]
Select Keyboard 1	7140	7140	[illegible]
Select Keyboard 2 plus Overlay with Interrupt on Key-hit	710[illegible]	710[illegible]*	000VVVFFFFFF
Select Keyboard 1 with Interrupt with Interrupt on Key-hit	7105	71[illegible]5*	000000[illegible]
Select Keyboard 1 with Interrupt on Carriage Return	7111	[illegible]111*	[illegible] Code)
Select Keyboard 1 with Interrupt on Tab	71[illegible]1	71[illegible]1*	[illegible] Code)
Select Radar Info to 160[illegible] with Interrupt on Receipt of Target Pulse	7141	7141*	[illegible] XX [illegible] YYYY [illegible] (0[illegible] 00 Future
Select Radar Info to Auxiliary on Receipt of a Target Pulse	7001	70[illegible]1	Same
Select Radar Info to 1604 on Receipt of a Target Pulse	7[illegible]02	[illegible]2*	Same
Select Radar Info to 160 on Receipt of a Target Pulse	7[illegible]0[illegible]*	[illegible]	Same
Select 160 Status Response	7[illegible]0*	70[illegible]	See Figure 7-[illegible] for 160 [illegible] Responses
Select n-Word Memory Update from 160	7[illegible]	70[illegible]	None-See Figure [illegible]-1 for [illegible] Info.
Select n-Word Memory Update from 160	7020*	7020	None-See Figure [illegible]-1 for [illegible] Info.

On 160 only - all manual inputs to the 160; on 160[illegible] only or both - all manual inputs to the 1604.

* Disabled selectively on 160 only or 160[illegible] only - [illegible] switch position

Figure [illegible]-[illegible] Select Function Codes for Control Functions

[illegible]	[illegible] 1604	[illegible] 160
Select Light 1A-On	7202	[illegible]
Select Light 1A-Off	7203	7203
Select Light 1B-On	[illegible]	7204
Select Light 1B-Off	7205	7205
Select Light 1C-On	7210	7210
Select Light 1C-Off	7211	7211
Select Light 1D-On	7220	7220
Select Light 1D-Off	7221	7221
Select Light 1E-On	7240	7240
Select Light 1E-Off	7241	7241
Select Light 2A-On	7302	7302
Select Light 2A-Off	7303	7303
↓	↓	↓
Select Light 6E-Off	7741	7741

Keyboard 2-Light Designation--

	1	2	3	4
A	*	*	*	*
B	*	*	*	*
C	*	*	*	*
D		*	*	*
E	*	*	*	*

	A	B	C	D	E
5	*	*	*	*	*
6	*	*	*	*	*

Figure 7-7
Select Function Codes for Light Feedback

8. System Implementation and Conclusions

The preceeding chapters described the design details of the functions to be performed by the DD-65. The complete block diagrams for the DD-56 are shown in Figures 8-1 and 8-2. The physical design of the unit requires over 1,500 logic circuit cards. In addition to these components, a number of power supplies and the deflection circuits for the display tubes are required. This large number of components, a number of power supplies and the deflection circuits for the display tubes are required. This large number of components prohibited a single cabinet design for the equipment. The digital logic has been placed in a separate cabinet which also contains all the low voltage power supplies for the digital circuits and the data line terminations from the computers. The operator's console contains the manual inputs and the display tubes as well as the high voltage power supplies to control the display tubes. Also incorporated in the operator's console are the digital to analog conversion circuits and the radar video circuits.

The entire system block diagram is shown in Figure 8-3. The pulse amplifier, video amplifier, and video quantizer are designed for implementation on the same size printed circuit cards as are used in the digital circuits. This allows these circuits to be contained within the logic cabinet of the DD-65. The final configuration of the DD-65 led to the proposed placement of the equipment in the Digital Automation and Control Laboratory as shown in Figure 8-4. The installation should be completed by August 1962.

The system, as designed, allows a great deal of programming flexibility and, therefore, a similar flexibility in respect to use of the operator's console. No attempt will be made here to flow-chart or dictate the type of system programs to be used with the DD-65, but a broad overview of possible functions will be undertaken. The discussion will be slanted toward specification of labels for the various overlays and operator keys. See Figure 8-5 for a diagram of entire operator's console.

The basic set of eight overlays could be specified as follows:

a. Air survelence and flight following
b. Air intercept and control
c. Program composition and de-bugging
d. Servomechanism design
e. Network synthesis
f. Library information retrieval and update
g. Linear programming package
h. Statistical analysis package

Additional sets of overlays could be used by merely changing the system library tape in the computing center. These overlays have twenty unique function keys available for use which have the labels associated with them changed each time the overlay is changed. These labels and, hence, the programmed functions should include only those functions which are not common to all usage overlays.

The individual labels and associated programs can be determined only by actually outlining each overlay program in considerable detail. A few possible functions that could be associated with the

"programming" overlay are the selection of the various languages to be used for coding. These language select keys would set up a format subroutine for accepting "symbol keyboard" information. For instance, the "tab" key would produce character spacing which would be compatible with the format normally used to input the language to the computer. Further "step process" keys could be labeled for the storing of a completed program on a magnetic tape library or for a "trace" mode of running for de-bugging purposes.

Those functions which are common to all overlays are to be controlled by the ten function keys which are associated with light feedbacks, but whose labels are not changed with the overlay change. The possible set of functions to be programmed with these keys are:

a. Tube "0" display

b. Tube "1" display

c. "Display" track ball

d. "Hook" track ball

e. "Drop" track ball

f. Enter data

g. Delete data

h. Start process

i. Stop process

j. Load library

These functions are tentative, but the set of functions described are common to all the proposed overlays, and the subroutines involved should not take many cells of the memory to implement. The track ball sequence, as proposed, will entail calling for the dis-

play of the track ball on a particular tube, and then the operator can move the displayed "TB" symbol to the desired position by movement of the track ball. The "hook" track ball can then be executed which can have various meanings depending on the usage overlay. Possible uses of "hook" would be to insert a point or symbol at the designated spot on the display or the process could be reversed, and information concerning the point which is designated by the "TB" symbol could be displayed. The "drop" track ball could be executed after either a "display" or "hook". This function command could mean to delete a symbol or point from the display or drop the "TB" symbol and/or the amplifying information called up by the hook. The "Load", "Start", and "Stop" functions are proposed to be associated with the handling of display data within the computer. For instance, to enter a line of data could mean to place it into permanent storage location for processing after the temporary (for display purposes) information has been verified as correct.

The remaining four function keys are to be marked with direction arrows and are proposed to be used to move an editing symbol over the chosen display tube for purposes of locating the position for typing in or erasing information.

The actual operation of a system as proposed would require an overlay to be inserted and a library load executed. The computer, when ready to commence, would light the "start" process light. The operator, upon depressing the "start" process button, causes the computer to drop the selected light and start through the executive program. Upon reaching various points in the programs where infor-

mation is needed from the operator, various lights or groups of lights are selected "on" by the computer. The function labels associated with the lights outline the required action or inputs to be initiated by the operator. In this manner of reply-request-display, the man can thread through the programs in close association with the computer until the operator chooses to stop the process by depressing the "stop" function key.

It is felt that the flexibility in usage of the command console and the speed and packing density of the display information will provide an experimental device for man-computer systems which will not rapidly become obsolescent.

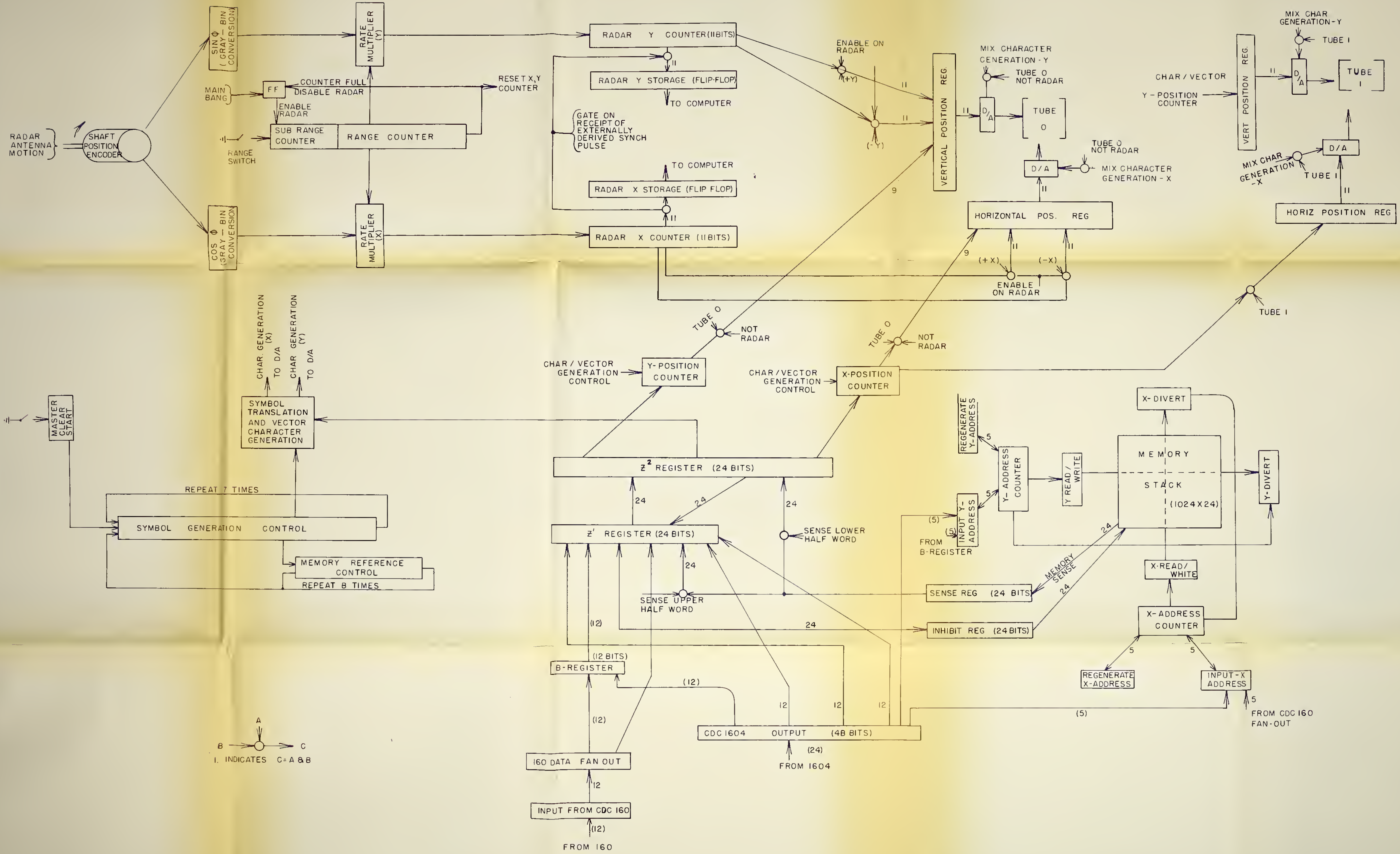
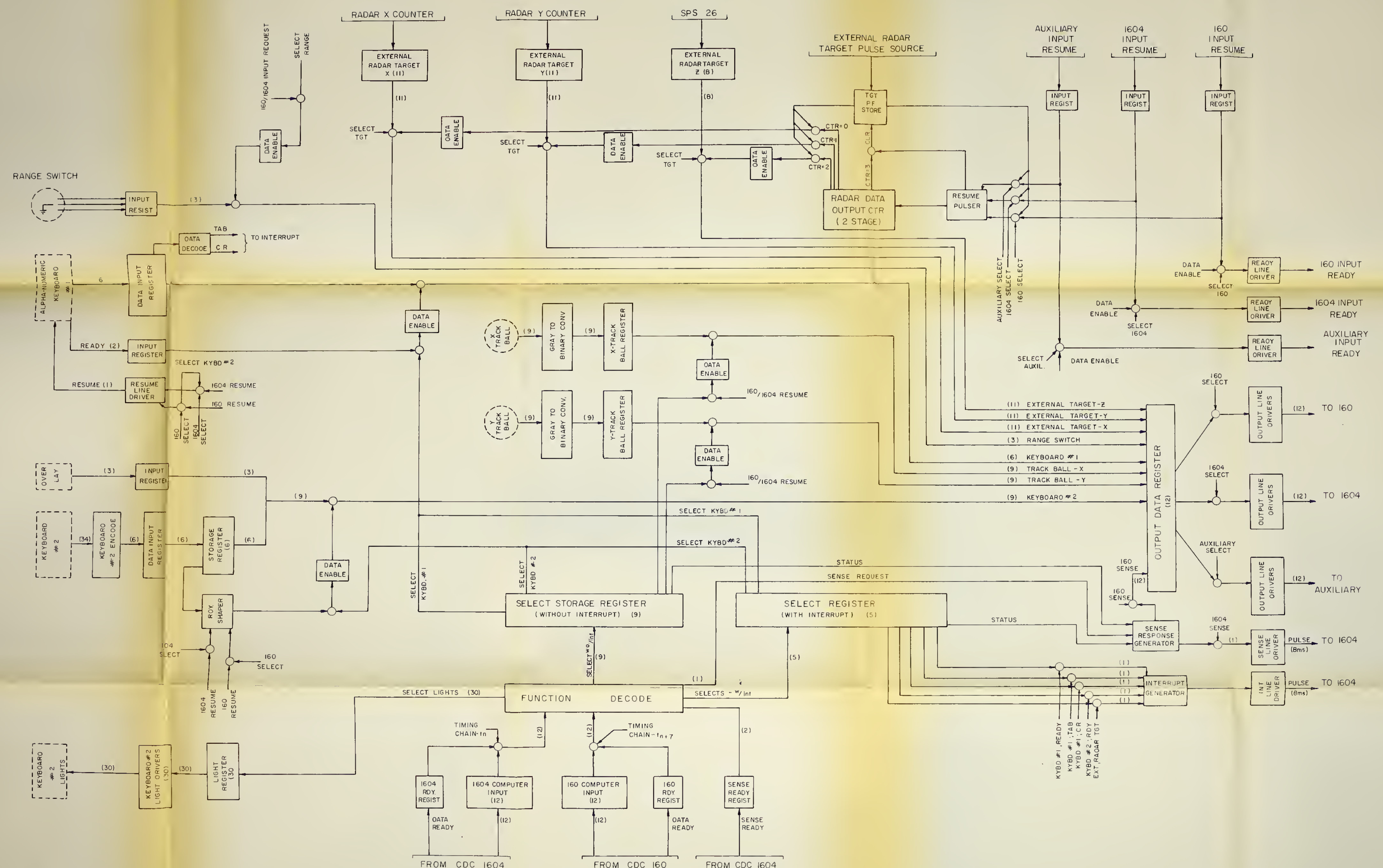
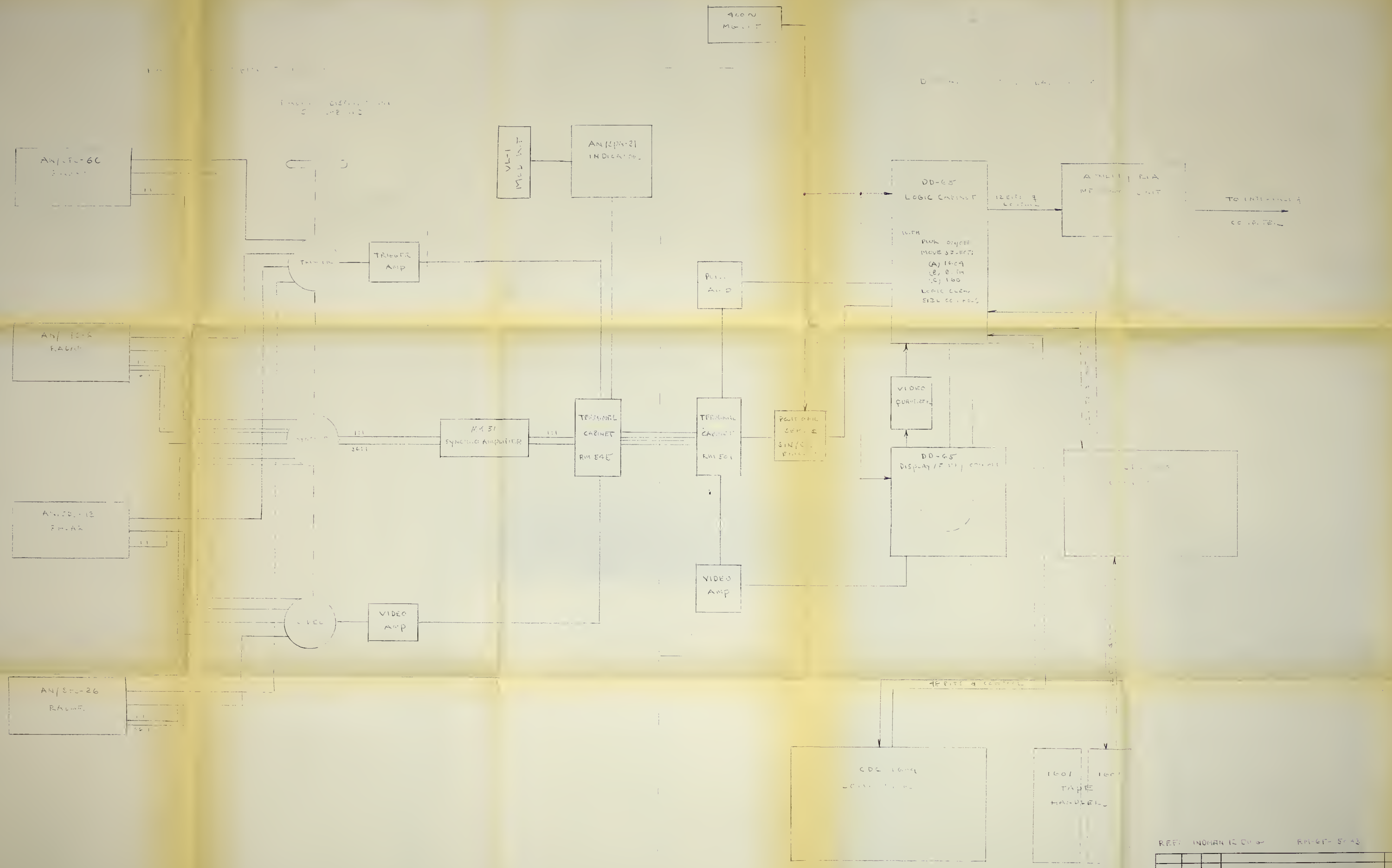


FIG. B-1 BLOCK DIAGRAM OF THE SYMBOL & RADAR GENERATORS & THE MEMORY





REF: INDMAN 12 DWG RM-61-5-43

REVISION	DATE	APPD	DESCRIPTION	BY

Industrial Manager, USN, 12th Naval District
ELECTRONICS DEPARTMENT

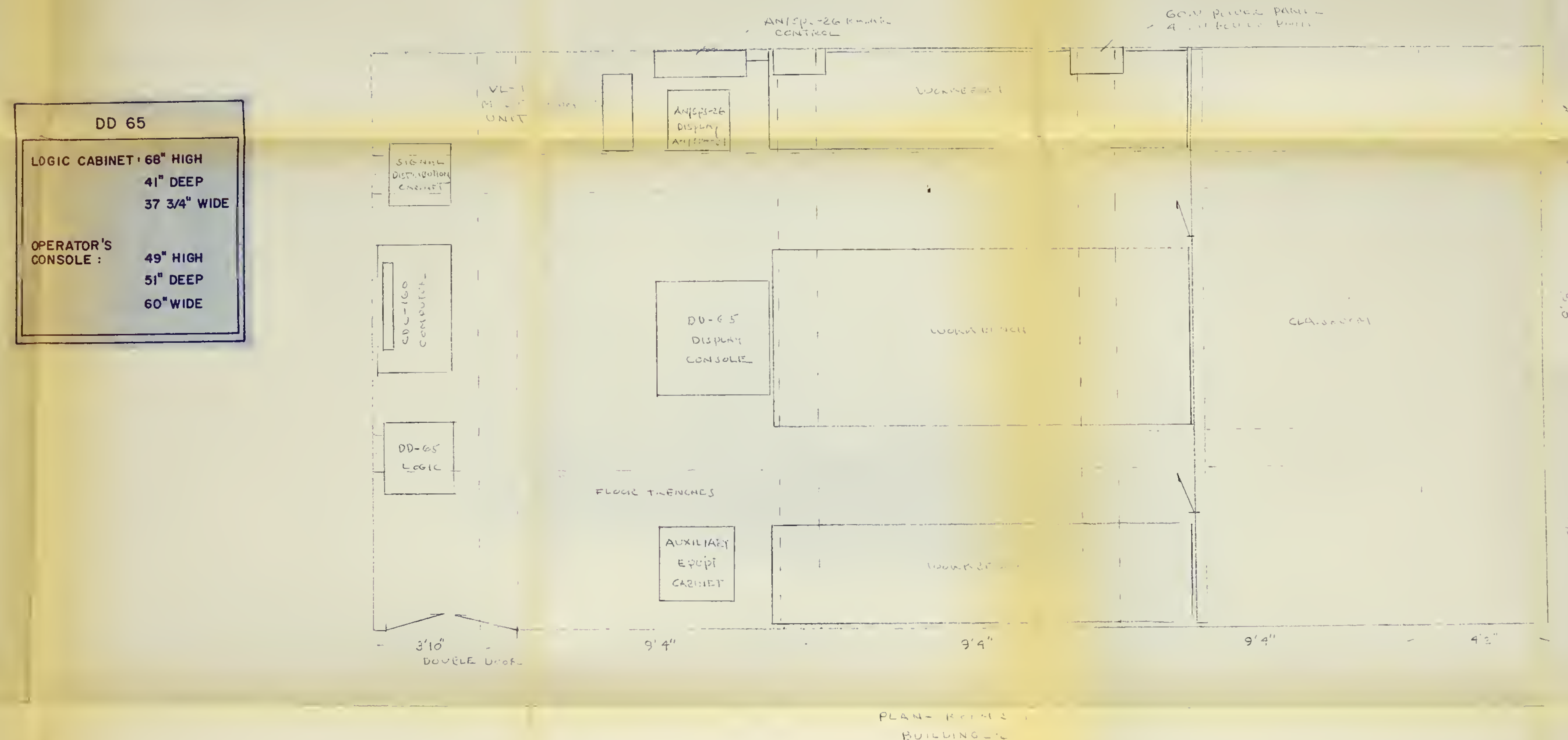
DES.
DWN.
CHK.
PROJ. ENG.
BRANCH HD.
DIVISION HD.
SCALE:
SHEET 1 OF 3
DATE APRIL 6
SATISFACTORY TO ____ USN FOR ____
DATE

U.S. NAVAL POSTGRADUATE SCHOOL
DIGITAL CONTROL LABORATORY
COMPUTER COMMUNICATIONS & DISPLAY SYSTEM

APPROVED ____ ELECTRONICS ASST. FOR INDMAN 12ND

INDMAN 12ND SKETCH NO.

FIG. 8-3 BLOCK DIAGRAM OF THE ENTIRE SYSTEM



REVISION | DATE | APPD | DESCRIPTION | BY

Industrial Manager, USN, 12th Naval District
ELECTRONICS DEPARTMENT

DES.
DWN.
CHK.
PROJ. ENG.
BRANCH HD.
DIVISION HD.
SCALE NO SCALE
SHEET 2 OF 2
DATE
SATISFACTORY TO
FOR
USN
DATE

APPROVED
ELECTRONICS ASST.
FOR INDMAN 12ND

INDMAN 12ND SKETCH NO.

FIG 8-4 PROPOSED EQUIPMENT LAYOUT FOR THE DIGITAL CONTROL & AUTOMATION LABORATORY

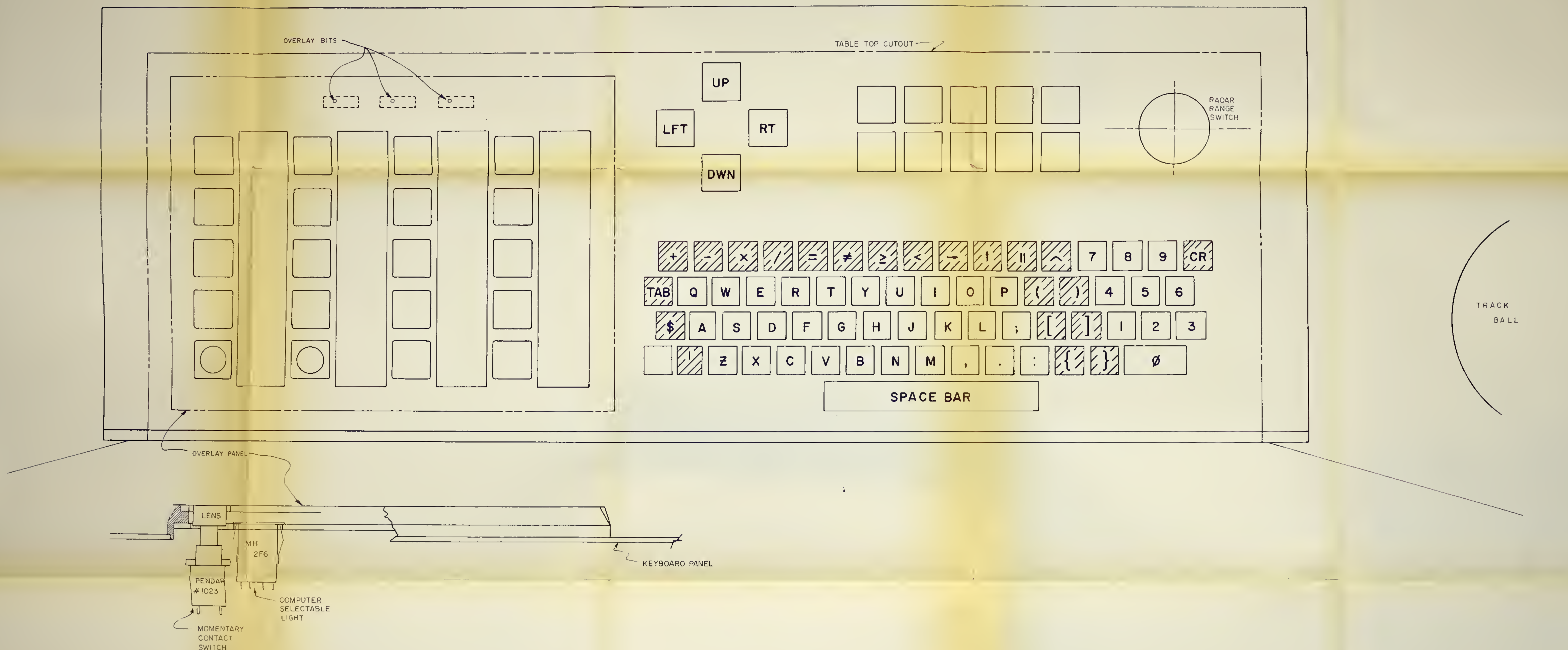


FIG. 8-5 LAYOUT OF THE OPERATORS CONSOLE

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APPENDIX I

DESIGN MECHANIZATION PROGRAM

Description, use and coding of a Control Data Corporation 1604 program for mechanizing portions of the design of digital equipments using Control Data Corporation type logic cards and format.

This appendix is written in standard "Co-op"[1] program description form.

Examples of sample outputs and inputs are shown in Figures 4-4 through 4-7 of this thesis.

[1] "Co-op" is the Control Data Corporation 1604 user group organization.

A. IDENTIFICATION

Title: Card Assignment and Wiring List Assembler for Control Data Corporation Input File of Equations

Category: Logical Design Aid

Programmer: C. G. Lawson

Date: 30 January 1962

B. PURPOSE

This routine is a composite of two separate functions:

1. It completes a file of equations and assigns card types to each equation for a given set of input equations.

2. It also computes and lists a wiring table if chassis locations for each section are designated.

In order to accomplish the first function, a magnetic tape containing punched card images of the input equations are processed by compiling an input table for the entire set of equations. This table is then searched to make up a list of outputs for each card. The number of inputs and outputs are then counted and logic cards are assigned, based upon the constraints of the family of cards. Certain special card types may be designated in the equation statements by special symbols. The number of cards required are counted during this process, and any erroneous equations are noted. The output at this point is a magnetic tape having the original input equations, each followed by a line containing the card type and a list of output destinations. Also, for any erroneous equations a star is placed in the left column adjacent to the equations. Following the equation file on the tape is a list of the card types

and the total number of each required for the design.

The second part of the program adds to the output tape a wiring tabulation of the intercard wires. In order to make up "wire tabs" the location of each section must be designated. This is done by adding the location information to the punched card for each equation. The program is then run with jump key one set and with an input of a magnetic tape containing the punched card images of the equations and locations. When there is a choice of wiring between points, the program compares lengths and assigns the shortest interconnection possible. The output is now a magnetic tape which contains all of the output lists.

The purpose for separating the program outputs is due to consideration of design proceedures. In most cases the file of equations are written from logic diagrams which do not necessarily show all the output wires. The clarity of the diagrams is improved if fewer interconnection lines need be shown. Therefore, the type card cannot always be assigned before finding how many outputs are needed. Also, if the total number of outputs required are more than the legal possible number of outputs, paralleling of signals is necessary. These considerations dictate that the completion of a design be done in two parts. The first part is to find out the card types necessary and to point out any errors in the equations. The location for the sections may now be assigned based upon the knowledge of card types and, also, any corrections may be entered into the input equations by changing the erroneous punched cards. The new inputs will now allow the output of all the desired lists

for wiring the console.

D. USAGE

1. <u>Calling Sequence:</u>

   a. On bioctal tape at present time

   b. Start location =5000

   c. Successful completion leaves 10000 in U

2. <u>Arguments:</u> none

3. <u>Space required:</u> 1000 cells

4. <u>Temporary storage requirements:</u> 1500 + 18X (number of input equations)

5. <u>Alarms:</u> none

6. <u>Error returns:</u> none

7. <u>Error stops:</u> 5450 in U if output criteria not satisfied (may be restarted if desired as errors will be indicated on printout)

   105 in U if inconsistancies in designation are encountered

8. <u>Input and output tape mountings:</u>

   a. Input:

      (1) Source tape: CH 5 202

   b. Output:

      (1) Output tape A: CH 4 203

9. <u>Input and output formats:</u>

   a. Input: 80 character card image of input equations. Input equations written in standard JOE format (see references).

(1) Input for card assignment only (jump key 1 not set):

(a) Each term must consist of four alphanumeric characters.

(b) The function must be the first term of the equation.

(c) The only restrictions on spacing or locations on the card is that columns 73 through 80 be set aside for insertion of location when assigned.

(d) The following characters are defined as operators when used in a logical equation:

space + - * / ( ) _ , ' .

(e) All entries following . / ' * , ( ) are treated as remarks.

(f) A maximum of 16 input terms may be used in an equation

(g) A maximum of 100 outout uses will be compiled for a function

(h) When inserted anywhere following the equation, these symbols define unique types of cards:

. or space only	inverters (series 10 and 20)
*	flip-flops (series 30) (one flip-flop per card)
'	input cards (61) (three inverters per card)
/	output cards (62) (three inverters per card)
,	clock cards (01) (two oscillators per card)

(single inverter (S36) (three inverters per card)

) diode fanout (S0?) (three sets of three diodes each per card)

(i) If flip-flops (series 30) designated, the pair input equations should be adjacent, and the implicit input should be the first OR term.

(2) Input for complete program (jump key one set): In addition to (a) through (i) above, the location must be typed into columns 77 through 80 and should have the following format:

Input card column	77	78 and 79	80
Meaning	ROW	COLUMN	SECTION
Allowable contents	A thru R	01 thru 99	A for 10 series A or C or 20 and 30 series or clock S04 A, B or C for 60 series or S36

Columns 73 through 76 can be used to identify chassis.

b. Outputs: 120 character line image in program control format for listing on output tape A.

(1) Outputs for card assignment only (jump key 1 not set):

(a) comments lines where applicable

(b) input equation lines as read in

(c) output lines with card type followed by list of output locations (following each input line)

(d) tabulation of the number of cards necessary to

implement the design.

(e) If any errors occur, such as too many inputs or outputs, no assignment is made and an error symbol is placed in the output line (along with an error stop).

(2) Outputs for complete program (jump key one set):

(a) as above

(b) input equation lines minus the location information

(c) output lines with location and card type followed by list of output locations (following each input line)

(d) as above

(e) tabulation of wiring data containing the following:

(e-1) origin and destination by row, column and pin number, if an internal card or by designation if external input

(e-2) designations of the above origin and destinations

(e-3) wire length in inches

(e-4) separation of ANDed groups by symbol * in left column

10. Selective jump and stop settings:

a. First run: none - to obtain card types

b. Second run: Jump key one set - to allow processing of

location information

11. Timing: depends on number of input equations

12. Accuracy: not applicable

13. Cautions to user: No tape errors are checked in the routine.

14. Equipment configuration: 1604 with two 1607 units; 1607 tape mountings to include a "scratch tape" on Ch4 TU4

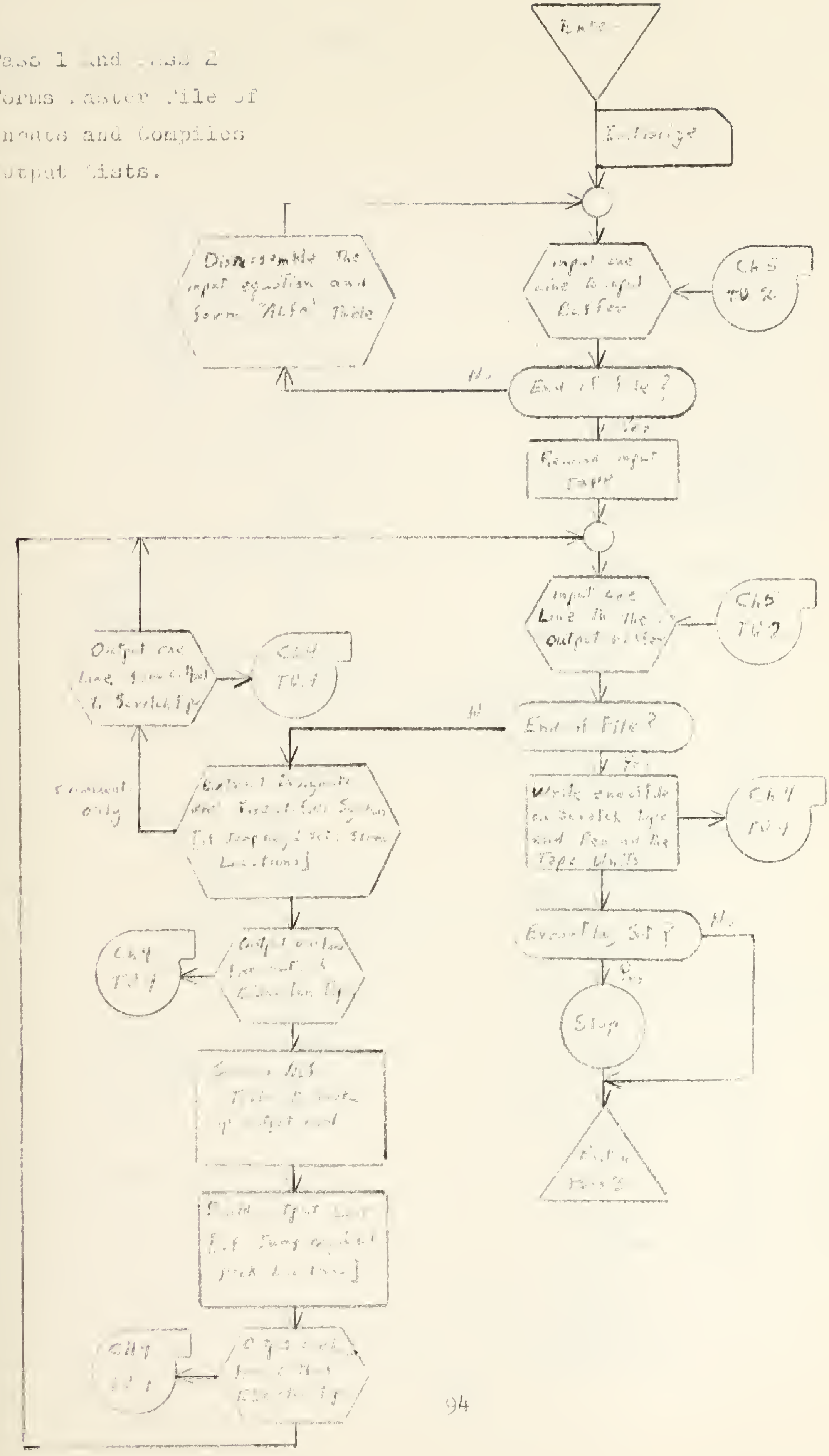
15. References:

a. 1604 Computer Instruction Book, Vol. 1, Description and Operations, Control Data Corporation

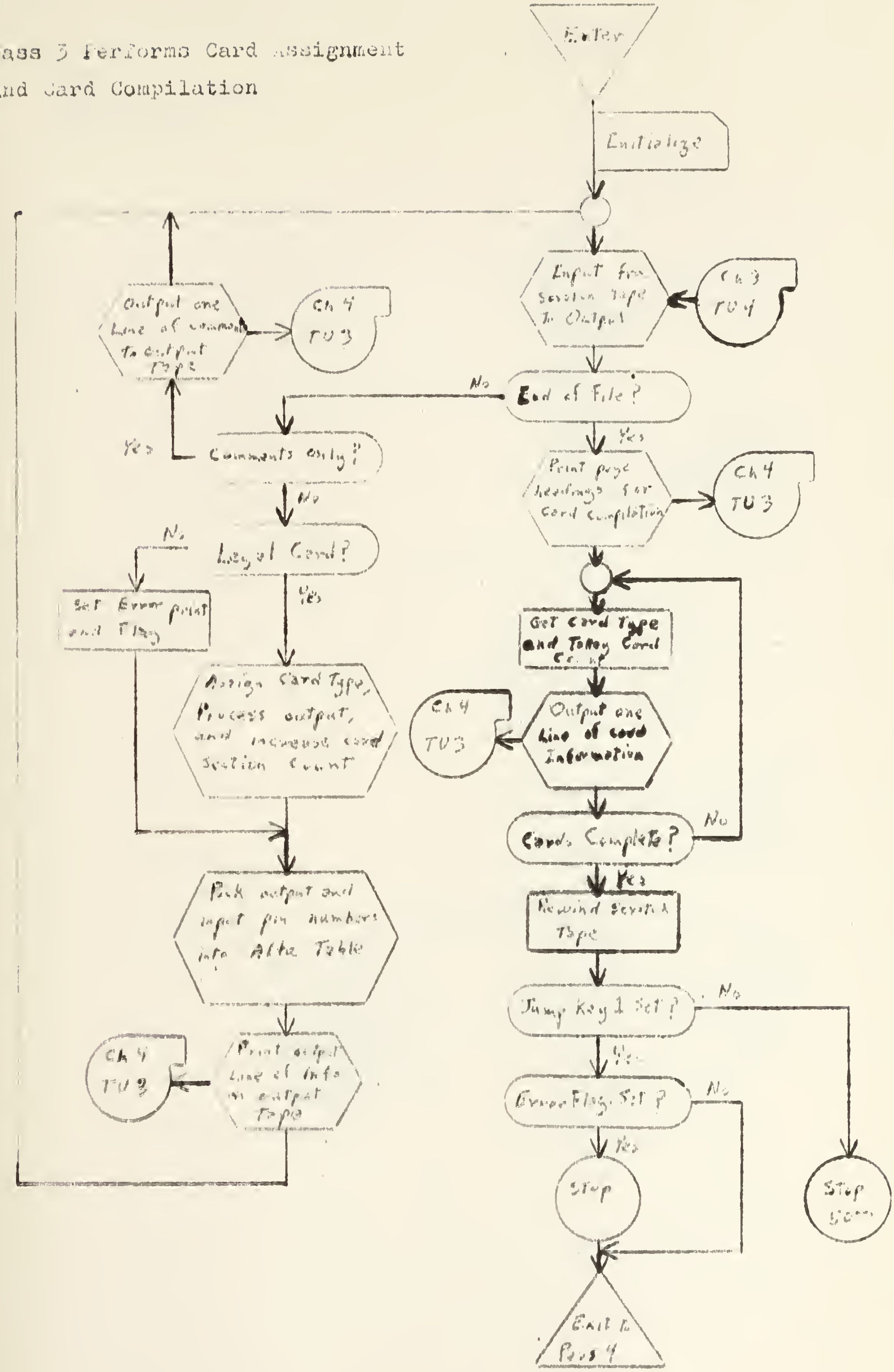
b. 1604 Computer Instruction Book, Vol. 2, Principals of Operations, Control Data Corporation

c. H. Loberman and A. Weinberger, Formal Procedures for Connecting Terminals with a Minimum Total Wire Length, J. Assoc. Computing Machinery, Vol. 4, no. 4, pp. 428-437, October, 1957

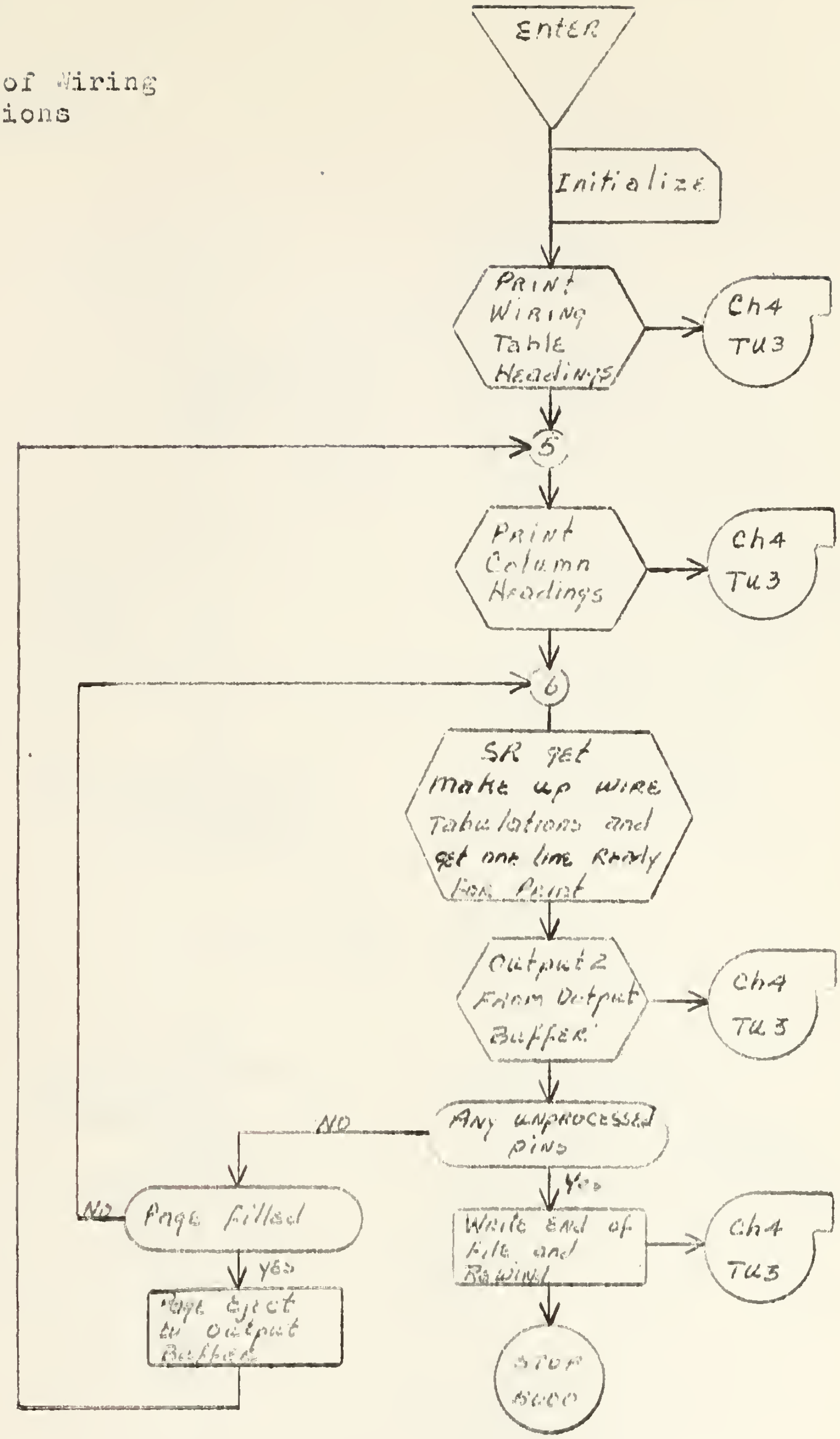
Pass 1 and Pass 2
Forms Master File of
Inputs and Compiles
Output Lists.



Pass 3 Performs Card Assignment and Card Compilation



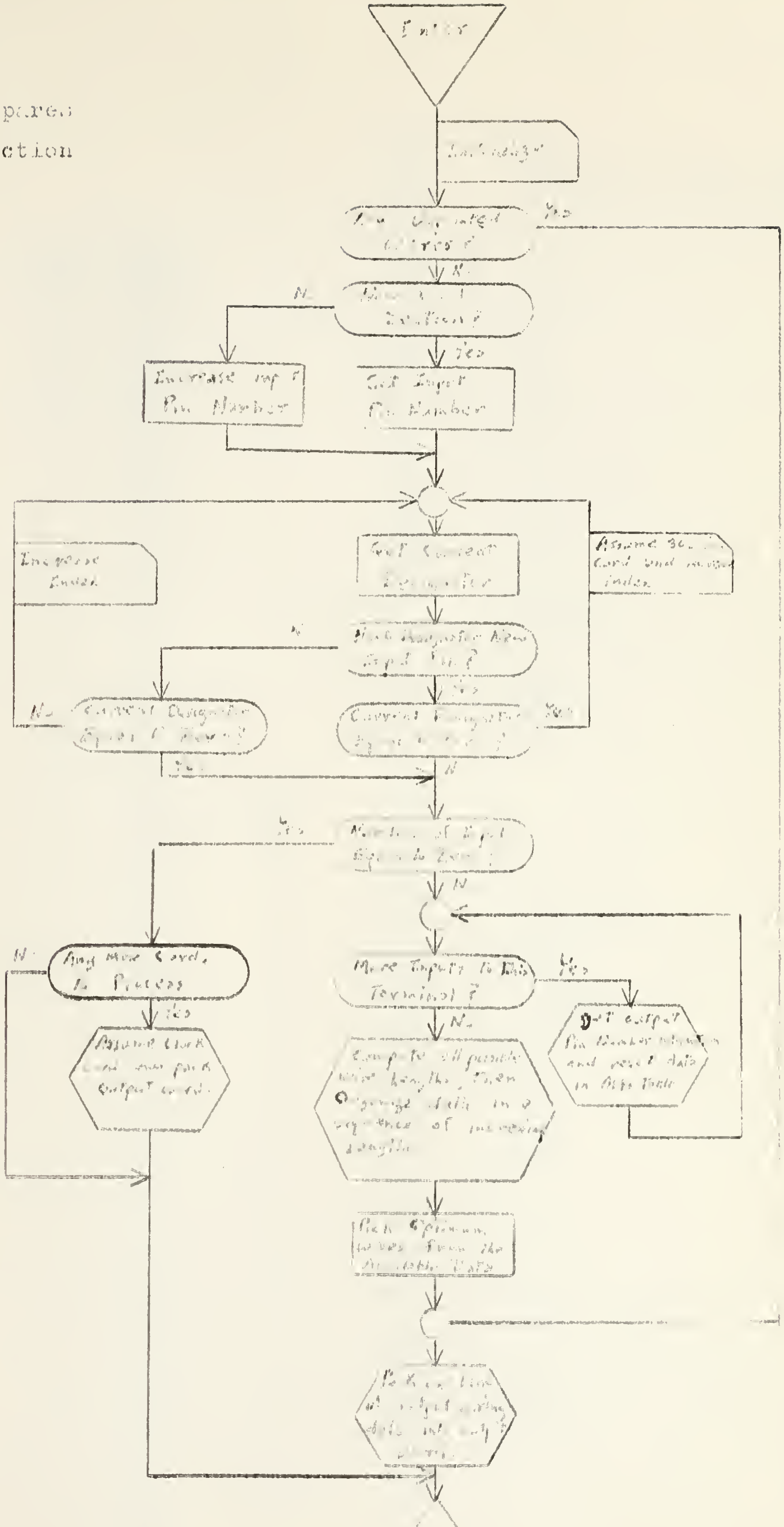
Pass 4
Makeup of Wiring
Tabulations



Subroutine [illegible]T

Chooses and Prepares

Best Wire Collection



```
                                        ORG    5000
                                        REM    PART ONE OF THE LOCI
                                        REM    SUBROUTINE WHICH COL
                                        REM    LOGICAL EQUATIONS AN
                                        REM    ON THE LINE IMMEDIAT
05000   50 1 00000                      ENI  1 0
        10 0 00000                      ENA  0 0
05001   20 1 10000                      STA  1 ANBUF
        50 0 00000                      ENI  0 0
05002   54 1 67700                      ISK  1 67700
        75 0 05001                      SLJ  0 /-1
05003   20 0 05253                      STA  0 FLAG
        20 0 05310                      STA  0 PAGE
05004   20 0 06067                      STA  0 WAIT
        20 0 06064                      STA  0 COUNT
05005   50 0 00000            INPUT     ENI  0 0
        74 7 52000                      EXF  7 52000
05006   10 0 05267                      ENA  0 INBUF+10D
        61 0 00005                      SAL  0 5
05007   74 0 52022                      EXF  0 52022
        74 7 52000                      EXF  7 52000
05010   74 5 05255                      EXF  5 INBUF
        74 7 52000                      EXF  7 52000
05011   74 7 52006                      EXF  7 52006
        75 0 05044                      SLJ  0 DISASS
05012   74 5 05267                      EXF  5 INBUF+10D
        50 0 00000                      ENI  0 0
05013   74 0 52005                      EXF  0 52005
        57 1 07226                      SIL  1 GOFER
05014   12 0 07226                      LDA  0 GOFER
        20 0 05242                      STA  0 TEMP+1
05015   75 4 05202                      SLJ  4 FILL
        50 0 00000                      ENI  0 0
05016   50 0 00000            ELEV      ENI  0 0
        74 7 52000                      EXF  7 52000
05017   10 0 05302                      ENA  0 OUTBUF+11D
        61 0 00005                      SAL  0 5
05020   74 0 52022                      EXF  0 52022
        74 7 52000                      EXF  7 52000
05021   74 5 05270                      EXF  5 OUTBUF+1
        74 7 52000                      EXF  7 52000
05022   74 7 52006                      EXF  7 52006
        75 0 05037                      SLJ  0 TWELVE
05023   74 5 05302                      EXF  5 OUTBUF+11D
        74 7 42000                      EXF  7 42000
05024   74 0 42042                      EXF  0 42042
        74 0 42003                      EXF  0 42003
05025   74 7 42000                      EXF  7 42000
        74 0 42005                      EXF  0 42005
05026   74 0 52005                      EXF  0 52005
        12 0 05253                      LDA  0 FLAG
05027   22 0 05456                      AJP  0 PASS3
        10 0 00000                      ENA  0 0
05030   20 0 05253                      STA  0 FLAG
        76 0 05456                      SLS  0 PASS3
05031   75 0 00000            OUTPUT    SLJ  0 0
        74 7 42000                      EXF  7 42000
05032   20 0 05246                      STA  0 TEMP+5
        72 0 05310                      RAO  0 PAGE
05033   10 0 05306                      ENA  0 OUTBUF+15D
        61 0 00004                      SAL  0 4
05034   74 0 42042                      EXF  0 42042
        74 7 42000                      EXF  7 42000
05035   74 4 05267                      EXF  4 OUTBUF
        74 7 42000                      EXF  7 42000
05036   12 0 05246                      LDA  0 TEMP+5
        75 0 05031                      SLJ  0 OUTPUT
05037   75 4 05077            TWELVE    SLJ  4 EXTRACT
        50 0 00000                      ENI  0 0
05040   75 4 05031                      SLJ  4 OUTPUT
        50 0 00000                      ENI  0 0
```

```
05041   12 0 05252              LDA  0 SPACE
        20 0 05267              STA  0 OUTBUF
05042   20 0 05305              STA  0 OUTBUF+14D
        12 0 05241              LDA  0 TEMP
05043   50 0 00000              ENI  0 0
        75 0 05125              SLJ  0 SEARCH
05044   50 2 00000    DISASS    ENI  2 0
        50 3 00000              ENI  3 0
05045   50 4 00000              ENI  4 0
        50 5 00000              ENI  5 0
05046   50 6 00000              ENI  6 0
        10 0 00000              ENA  0 0
05047   16 2 05255    ONE       LDQ  2 INBUF
        50 0 00000              ENI  0 0
05050   05 0 00006    TWO       ALS  0 6
        20 0 05241              STA  0 TEMP
05051   10 0 00000              ENA  0 0
        07 0 00006              LLS  0 6
05052   50 6 00013              ENI  6 11D
        50 0 00000              ENI  0 0
05053   64 6 05206              EQS  6 LIST
        75 0 05063              SLJ  0 THREE
05054   10 6 00000              ENA  6 0
        22 1 05056              AJP  1 /+2
05055   10 5 00000              ENA  5 0
        22 0 05072              AJP  0 FIVE+2
05056   10 6 00000              ENA  6 0
        15 0 05254              SUB  0 UNITS
05057   22 3 05071              AJP  3 FIVE+1
        51 6 77770              INI  6 -7
05060   55 6 05061              IJP  6 /+1
        75 0 05075              SLJ  0 OR
05061   55 6 05062              IJP  6 /+1
        75 0 05075              SLJ  0 OR
05062   10 0 00000              ENA  0 0
        75 0 05067              SLJ  0 FOUR
05063   70 0 05241    THREE     RAD  0 TEMP
        50 0 00000              ENI  0 0
05064   54 3 00003              ISK  3 3
        75 0 05067              SLJ  0 FOUR
05065   70 1 16000              RAD  1 ALFA
        51 5 00001              INI  5 1
05066   51 1 00001              INI  1 1
        10 0 00000              ENA  0 0
05067   54 4 00007    FOUR      ISK  4 7
        75 0 05050              SLJ  0 TWO
05070   54 2 00010    FIVE      ISK  2 10
        75 0 05047              SLJ  0 ONE
05071   54 5 00022              ISK  5 22
        75 0 05073              SLJ  0 /+2
05072   75 0 05005              SLJ  0 INPUT
        50 0 00000              ENI  0 0
05073   10 0 00000              ENA  0 0
        20 1 16000              STA  1 ALFA
05074   51 1 00001              INI  1 1
        75 0 05071              SLJ  0 /-3
05075   12 0 05455    OR        LDA  0 BIT48
        20 1 16000              STA  1 ALFA
05076   10 0 00000              ENA  0 0
        75 0 05067              SLJ  0 FOUR
05077   75 0 00000    EXTRACT   SLJ  0 0
        10 0 00000              ENA  0 0
05100   50 5 00000              ENI  5 0
        16 0 05270              LDQ  0 OUTBUF+1
05101   05 0 00006              ALS  0 6
        20 0 05241              STA  0 TEMP
05102   10 0 00000              ENA  0 0
        50 0 00000              ENI  0 0
05103   07 0 00006              LLS  0 6
        50 6 00013              ENI  6 11D
05104   64 6 05206              EQS  6 LIST
        75 0 05107              SLJ  0 /+3
05105   10 6 00000              ENA  6 0
```

```
        22 0 05172             AJP  0 TENA-1
05106   75 0 05102             SLJ  0 /-4
        50 0 00000             ENI  0 0
05107   70 0 05241             RAD  0 TEMP
        50 0 00000             ENI  0 0
05110   54 5 00003             ISK  5 3
        75 0 05101             SLJ  0 /-7
05111   50 3 00000             ENI  3 0
        50 2 00000             ENI  2 0
05112   75 5 05773             SLJ  5 MAKEX
        50 0 00000             ENI  0 0
05113   16 2 05270             LDQ  2 OUTBUF+1
        50 0 00000             ENI  0 0
05114   10 0 00000             ENA  0 0
        50 0 00000             ENI  0 0
05115   07 0 00006             LLS  0 6
        50 6 00007             ENI  6 7
05116   64 6 05206             EQS  6 LIST
        75 0 05120             SLJ  0 /+2
05117   75 0 05122             SLJ  0 /+3
        50 0 00000             ENI  0 0
05120   54 3 00007             ISK  3 7
        75 0 05114             SLJ  0 /-4
05121   54 2 00010             ISK  2 8D
        75 0 05113             SLJ  0 /-6
05122   12 6 05232             LDA  6 CARD21
        20 0 05305             STA  0 OUTBUF+14D
05123   12 6 05221             LDA  6 CHECK
        61 0 05247             SAL  0 EIGHT
05124   75 0 05077             SLJ  0 EXTRACT
        50 0 00000             ENI  0 0
05125   53 1 05242    SEARCH   LIL  1 TEMP+1
        50 3 00000             ENI  3 0
05126   16 0 06113    SIX      LDQ  0 LCMASK
        50 0 00000             ENI  0 0
05127   66 1 16000             MEQ  1 ALFA
        75 0 05141             SLJ  0 BUILD
05130   57 1 07226             SIL  1 GOFER
        12 0 07226             LDA  0 GOFER
05131   04 0 00000             ENQ  0 0
        22 0 05141             AJP  0 BUILD
05132   25 0 05230             DVI  0 INCRM
        23 0 05140             QJP  0 SEVEN
05133   57 1 07226             SIL  1 GOFER
        12 0 07226             LDA  0 GOFER
05134   21 0 05231             STQ  0 DECRM
        15 0 05231             SUB  0 DECRM
05135   20 0 05231             STA  0 DECRM
        53 2 05231             LIL  2 DECRM
05136   16 0 06113             LDQ  0 LCMASK
        44 2 16000             LPL  2 ALFA
05137   20 3 05311             STA  3 BETA
        51 3 00001             INI  3 1
05140   12 0 05241    SEVEN    LDA  0 TEMP
        75 0 05126             SLJ  0 SIX
05141   75 4 05202    BUILD    SLJ  4 FILL
        50 0 00000             ENI  0 0
05142   75 1 05143             SLJ  1 /+1
        75 0 05144             SLJ  0 /+2
05143   12 0 06066             LDA  0 HOLD
        20 0 05270             STA  0 OUTBUF+1
05144   55 3 05145             IJP  3 /+1
        75 0 05167             SLJ  0 PRNONE
05145   10 3 00000             ENA  3 0
        15 0 05247             SUB  0 EIGHT
05146   22 3 05150             AJP  3 /+2
        12 0 05251             LDA  0 STAR
05147   20 0 05267             STA  0 OUTBUF
        72 0 05253             RAO  0 FLAG
05150   75 0 05152             SLJ  0 /+2
        50 0 00000             ENI  0 0
05151   75 4 05202             SLJ  4 FILL
        50 0 00000             ENI  0 0
```

```
05152   50 4 00002 .          ENI   4  2
        10 3 00000            ENA   3  0
05153   60 0 05162            SAU   0  NINE+5
        60 0 05171            SAU   0  TEN
05154   50 3 00000            ENI   3  0
        50 0 00000            ENI   0  0
05155   16 0 05250   NINE     LDQ   0  COMMA
        12 3 05311            LDA   3  BETA
05156   07 0 00030            LLS   0  24D
        50 0 00000            ENI   0  0
05157   20 4 05270            STA   4  OUTBUF+1
        50 0 00000            ENI   0  0
05160   54 4 00015            ISK   4  13D
        75 0 05171            SLJ   0  TEN
05161   75 4 05031            SLJ   4  OUTPUT
        50 0 00000            ENI   0  0
05162   54 3 00000            ISK   3  0
        75 0 05164            SLJ   0  *+2
05163   75 0 05173            SLJ   0  TENA
        50 0 00000            ENI   0  0
05164   75 4 05202            SLJ   4  FILL
        50 0 00000            ENI   0  0
05165   12 0 05232            LDA   0  CARD21
        20 0 05270            STA   0  OUTBUF+1
05166   50 4 00002            ENI   4  2
        75 0 05155            SLJ   0  NINE
05167   12 0 05306   PRNONE   LDA   0  NONE
        20 0 05272            STA   0  OUTBUF+3
05170   75 0 05172            SLJ   0  TEN+1
        50 0 00000            ENI   0  0
05171   54 3 00000   TEN      ISK   3  0
        75 0 05155            SLJ   0  NINE
05172   75 4 05031            SLJ   4  OUTPUT
        50 0 00000            ENI   0  0
05173   75 4 05202   TENA     SLJ   4  FILL
        50 0 00000            ENI   0  0
05174   75 4 05031            SLJ   4  OUTPUT
        50 0 00000            ENI   0  0
05175   20 0 05246            STA   0  TEMP+5
        10 0 00110            ENA   0  72D
05176   65 0 05310            THS   0  PAGE
        75 0 05016            SLJ   0  ELEV
05177   10 0 00000            ENA   0  0
        20 0 05310            STA   0  PAGE
05200   12 0 05307            LDA   0  EJECT
        20 0 05267            STA   0  OUTBUF
05201   12 0 05246            LDA   0  TEMP+5
        75 0 05016            SLJ   0  ELEV
05202   75 0 00000   FILL     SLJ   0  0
        50 5 00000            ENI   5  0
05203   12 0 05252            LDA   0  SPACE
        20 5 05267            STA   5  OUTBUF
05204   54 5 00016            ISK   5  14D
        75 0 05203            SLJ   0  *-1
05205   75 0 05202            SLJ   0  FILL
        50 0 00000            ENI   0  0
05206   00 0 00000   LIST     OCT      73
        00 0 00073
05207   00 0 00000            OCT      54
        00 0 00054
05210   00 0 00000            OCT      53
        00 0 00053
05211   00 0 00000            OCT      21
        00 0 00021
05212   00 0 00000            OCT      33
        00 0 00033
05213   00 0 00000            OCT      34
        00 0 00034
05214   00 0 00000            OCT      74
        00 0 00074
05215   00 0 00000            OCT      60
        00 0 00060
05216   00 0 00000            OCT      13
```

```
                00 0 00013 .
05217           00 0 00000                     OCT     14
                00 0 00014
05220           00 0 00000                     OCT     20
                00 0 00020
05221           00 0 00000     CHECK           OCT     10
                00 0 00010
05222           00 0 00000                     OCT     5
                00 0 00005
05223           00 0 00000                     OCT     2
                00 0 00002
05224           00 0 00000                     OCT     1
                00 0 00001
05225           00 0 00000                     OCT     5
                00 0 00005
05226           00 0 00000                     OCT     1
                00 0 00001
05227           00 0 00000                     OCT     3
                00 0 00003
05230           00 0 00000     INCRM           OCT     22
                00 0 00022
05231           00 0 00000     DECRM           BSS     1
                00 0 00000
05232           20 2 02020     CARD21          BCD     /          .
                20 2 02073
05233           20 2 02020     CARD31          BCD     /          *
                20 2 02054
05234           20 2 02020     CARD61          BCD     /          $
                20 2 02053
05235           20 2 02020     CARD62          BCD     /          /
                20 2 02021
05236           20 2 02020     CARD01          BCD     /          ,
                20 2 02033
05237           20 2 02020     CARDS36         BCD     /          (
                20 2 02034
05240           20 2 02020     CARDS04         BCD     /          )
                20 2 02074
05241           00 0 00000     TEMP            BSS     6
                00 0 00000
05247           00 0 00000     EIGHT           OCT     10
                00 0 00010
05250           33 2 02020     COMMA           BCD     /,
                20 2 02020
05251           20 2 02020     STAR            BCD     /       *
                20 5 42020
05252           20 2 02020     SPACE           BCD     /
                20 2 02020
05253           00 0 00000     FLAG            BSS     1
                00 0 00000
05254           00 0 00000     UNITS           OCT     7
                00 0 00007
05255           00 0 00000     INBUF           BSS     10D
                00 0 00000
05267           00 0 00000     OUTBUF          BSS     15D
                00 0 00000
05306           45 4 64565     NONE            BCD     /NONE
                20 2 02020
05307           01 2 02020     EJECT           BCD     /1
                20 2 02020
05310           00 0 00000     PAGE            BSS     1
                00 0 00000
05311           00 0 00000     BETA            BSS     100D
                00 0 00000
05455           60 0 00000     BIT48           OCT     6000000000000000
                00 0 00000
                                               REM     CARD ASSIGNMENT ROUTINE
05456           50 1 00032     PASS3           ENI   1 26D
                10 0 00000                     ENA   0 0
05457           20 1 06027                     STA   1 ICOUNT
                55 1 05457                     IJP   1 /
05460           75 4 05700     PASS3A          SLJ   4 INPUT2
                50 0 00000                     ENI   0 0
05461           74 7 32006                     EXF   7 32006
```

```
        75 0 05552            SLJ  0 TEST
05462   74 3 05306            EXF  3 OUTBUF+150
        75 4 05202            SLJ  4 FILL
05463   12 0 06010            LDA  0 PAGEJ
        20 0 05267            STA  0 OUTBUF
05464   75 4 05705            SLJ  4 OUTPUT2
        50 0 00000            ENI  0 0
05465   75 4 05717            SLJ  4 CLRBUF
        50 0 00000            ENI  0 0
05466   10 0 06140            ENA  0 HEAD1
        60 0 05713            SAU  0 MSG+1
05467   12 0 06012            LDA  0 LNGTH1
        60 0 05714            SAU  0 MSG+2
05470   75 4 05712            SLJ  4 MSG
        50 0 00000            ENI  0 0
05471   75 4 05717            SLJ  4 CLRBUF
        50 0 00000            ENI  0 0
05472   10 0 06150            ENA  0 HEAD2
        60 0 05713            SAU  0 MSG+1
05473   12 0 06013            LDA  0 LNGTH2
        60 0 05714            SAU  0 MSG+2
05474   75 4 05712            SLJ  4 MSG
        50 0 00000            ENI  0 0
05475   75 4 05717            SLJ  4 CLRBUF
        50 0 00000            ENI  0 0
05476   10 0 06155            ENA  0 HEAD3
        60 0 05713            SAU  0 MSG+1
05477   12 0 06014            LDA  0 LNGTH3
        60 0 05714            SAU  0 MSG+2
05500   75 4 05712            SLJ  4 MSG
        50 0 00000            ENI  0 0
05501   50 5 00000            ENI  5 0
        75 4 05717            SLJ  4 CLRBUF
05502   12 0 05252            LDA  0 SPACE
        20 0 05274            STA  0 OUTBUF+5
05503   20 0 05275            STA  0 OUTBUF+6
        50 0 00000            ENI  0 0
05504   12 5 06116            LDA  5 CARD
        20 0 05271            STA  0 OUTBUF+2
05505   12 5 06027            LDA  5 ICOUNT
        75 4 05512            SLJ  4 OCTBCD
05506   54 5 00021            ISK  5 17D
        75 0 05502            SLJ  0 /-4
05507   74 0 32005            EXF  0 32005
        12 0 05253            LDA  0 FLAG
05510   75 1 05511            SLJ  1 /+1
        76 0 05000            SLS  0 5000
05511   22 0 06163            AJP  0 PASS4
        76 0 06163            SLS  0 PASS4
05512   75 0 00000    OCTBCD  SLJ  0 0
        50 6 00000            ENI  6 0
05513   65 0 06020            THS  0 RFR03
        51 6 00001            INI  6 1
05514   65 0 06017            THS  0 RFR02
        51 6 00001            INI  6 1
05515   65 0 06016            THS  0 RFR01
        51 6 00001            INI  6 1
05516   65 0 06015            THS  0 RFR00
        51 6 00001            INI  6 1
05517   55 6 05520            IJP  6 /+1
        75 0 05532            SLJ  0 FRACT
05520   16 6 06021            LDQ  6 MASK
        21 0 05243            STQ  0 TEMP+2
05521   04 0 00000            ENQ  0 0
        21 0 05241            STQ  0 TEMP
05522   04 0 00000            ENQ  0 0
        25 6 06015            DVI  6 RFR00
05523   22 1 05524            AJP  1 /+1
        12 0 06107            LDA  0 ZERO
05524   20 0 05244            STA  0 TEMP+3
        12 0 05241            LDA  0 TEMP
05525   05 0 00006            ALS  0 6
        14 0 05244            ADD  0 TEMP+3
```

```
05526    20 0 05241              STA   0 TEMP
         21 0 05244              STQ   0 TEMP+3
05527    12 0 05244              LDA   0 TEMP+3
         55 6 05522              IJP   6 /-5
05530    12 0 05241              LDA   0 TEMP
         14 0 05243              ADD   0 TEMP+2
05531    20 0 05274              STA   0 OUTBUF+5
         50 0 00000              ENI   0 0
05532    10 5 00000   FRACT      ENA   5 0
         15 0 06026              SUB   0 TRIP
05533    22 2 05542              AJP   2 THIRD
         10 5 00000              ENA   5 0
05534    15 0 06025              SUB   0 DCUB
         22 2 05547              AJP   2 HALF
05535    12 0 05274   ITEST      LDA   0 OUTBUF+5
         15 0 05252              SUB   0 SPACE
05536    22 1 05540              AJP   1 OUTLINE
         12 0 05306              LDA   0 NONE
05537    20 0 05274              STA   0 OUTBUF+5
         50 0 00000              ENI   0 0
05540    75 4 05705   OUTLINE    SLJ   4 OUTPUT2
         50 0 00000              ENI   0 0
05541    75 0 05512              SLJ   0 OCTBCD
         50 0 00000              ENI   0 0
05542    12 5 06040   THIRD      LDA   5 FCOUNT-9D
         22 0 05535              AJP   0 ITEST
05543    64 0 06015              EQS   0 RFROO
         75 0 05545              SLJ   0 /+2
05544    12 0 06072              LDA   0 ATHIRD
         75 0 05546              SLJ   0 /+2
05545    12 0 06073              LDA   0 BTHIRD
         50 0 00000              ENI   0 0
05546    20 0 05275              STA   0 OUTBUF+6
         75 0 05540              SLJ   0 OUTLINE
05547    12 5 06040   HALF       LDA   5 FCOUNT-9D
         22 0 05535              AJP   0 ITEST
05550    12 0 06074              LDA   0 AHALF
         20 0 05275              STA   0 OUTBUF+6
05551    75 0 05540              SLJ   0 OUTLINE
         50 0 00000              ENI   0 0
05552    12 0 05305   TEST       LDA   0 OUTBUF+14D
         50 1 00000              ENI   1 0
05553    64 0 05252              EQS   0 SPACE
         75 0 05560              SLJ   0 TEST2
05554    75 0 05556              SLJ   0 /+2
         50 0 00000              ENI   0 0
05555    75 5 05734   TEST1      SLJ   5 OUTPIN
         50 0 00000              ENI   0 0
05556    75 4 05705              SLJ   4 OUTPUT2
         50 0 00000              ENI   0 0
05557    75 0 05460              SLJ   0 PASS3A
         50 0 00000              ENI   0 0
05560    64 0 05234   TEST2      EQS   0 CARD61
         75 0 05570              SLJ   0 NEXT1
05561    75 4 05705   ICCD       SLJ   4 OUTPUT2
         50 0 00000              ENI   0 0
05562    75 4 05700              SLJ   4 INPUT2
         50 0 00000              ENI   0 0
05563    12 1 06134              LDA   1 CARD+14D
         20 0 05271              STA   0 OUTBUF+2
05564    72 1 06056              RAO   1 FCOUNT+5
         15 0 06077              SUB   0 TRIO
05565    22 0 05566              AJP   0 /+1
         75 0 05555              SLJ   0 TEST1
05566    10 0 00000              ENA   0 0
         20 1 06056              STA   1 FCOUNT+5
05567    72 1 06045              RAO   1 ICOUNT+14D
         75 0 05555              SLJ   0 TEST1
05570    64 0 05235   NEXT1      EQS   0 CARD62
         75 0 05655              SLJ   0 NEXT2
05571    50 1 00001              ENI   1 1
         75 0 05561              SLJ   0 ICCD
05572    64 0 05233   TEST3      EQS   0 CARD51
```

```
         75 0 05616                SLJ  0 TEST4
05573    50 6 00012                ENI  6 10D
         75 4 05723                SLJ  4 ORCOUNT
05574    75 4 05705                SLJ  4 OUTPUT2
         50 0 00000                ENI  0 0
05575    75 4 05700                SLJ  4 INPUT2
         50 0 00000                ENI  0 0
05576    12 0 06063                LDA  0 ORCNT
         50 0 00000                ENI  0 0
05577    64 0 06100                EQS  0 DUO
         75 0 05612                SLJ  0 TRY2
05600    12 1 06124    FFCD        LDA  1 CARD+6
         20 0 05271                STA  0 OUTBUF+2
05601    10 0 00001                ENA  0 1
         20 0 06070                STA  0 FFFLG
05602    72 1 06035                RAO  1 ICOUNT+6
         75 5 05734                SLJ  5 OUTPIN
05603    75 4 05705                SLJ  4 OUTPUT2
         50 0 00000                ENI  0 0
05604    75 4 05700                SLJ  4 INPUT2
         50 0 00000                ENI  0 0
05605    75 4 05705                SLJ  4 OUTPUT2
         50 0 00000                ENI  0 0
05606    75 4 05700                SLJ  4 INPUT2
         50 0 00000                ENI  0 0
05607    12 1 06124                LDA  1 CARD+6
         20 0 05271                STA  0 OUTBUF+2
05610    12 0 05455                LDA  0 BIT48
         20 2 16001                STA  2 ALFA+1
05611    75 0 05555                SLJ  0 TEST1
         50 0 00000                ENI  0 0
05612    64 0 06077    TRY2        EQS  0 TRIO
         75 0 05614                SLJ  0 TRY3
05613    50 1 00001                ENI  1 1
         75 0 05600                SLJ  0 FFCD
05614    64 0 06076    TRY3        EQS  0 QUAD
         75 0 05665                SLJ  0 ERROR1
05615    50 1 00002                ENI  1 2
         75 0 05600                SLJ  0 FFCD
05616    64 0 05232    TEST4       EQS  0 CARD21
         75 0 05661                SLJ  0 TEST5
05617    50 6 00012                ENI  6 10D
         75 4 05723                SLJ  4 ORCOUNT
05620    75 4 05705                SLJ  4 OUTPUT2
         50 0 00000                ENI  0 0
05621    75 4 05700                SLJ  4 INPUT2
         50 0 00000                ENI  0 0
05622    75 4 05672                SLJ  4 OUTCOUNT
         50 0 00000                ENI  0 0
05623    12 0 06063                LDA  0 ORCNT
         50 0 00000                ENI  0 0
05624    64 0 06075                EQS  0 QUINT
         75 0 05632                SLJ  0 TRY6
05625    12 1 06101    UNCD        LDA  1 OUTEND
         50 0 00000                ENI  0 0
05626    65 0 06062                THS  0 OUTCNT
         75 0 05630                SLJ  0 /+2
05627    75 0 05670                SLJ  0 ERROR2
         50 0 00000                ENI  0 0
05630    12 1 06122                LDA  1 CARD+4
         20 0 05271                STA  0 OUTBUF+2
05631    72 1 06033                RAO  1 ICOUNT+4
         75 0 05555                SLJ  0 TEST1
05632    64 0 06102    TRY6        EQS  0 SEXT
         75 0 05634                SLJ  0 INV1
05633    50 1 00001                ENI  1 1
         75 0 05625                SLJ  0 UNCD
05634    64 0 06015    INV1        EQS  0 REROO
         75 0 05647                SLJ  0 INV2
05635    12 1 06075    INCD        LDA  1 QUINT
         50 0 00000                ENI  0 0
05636    65 0 06062                THS  0 OUTCNT
         75 0 05641                SLJ  0 SER20
```

```
05637     12 1 06116              LDA   1 CARD
          20 0 05271              STA   0 OUTBUF+2
05640     72 1 06027              RAO   1 ICOUNT
          75 0 05555              SLJ   0 TEST1
05641     51 1 00011   SER20      INI   1 9D
          12 1 06116              LDA   1 CARD
05642     20 0 05271              STA   0 OUTBUF+2
          72 1 06040              RAO   1 ICOUNT+9D
05643     15 0 06100              SUB   0 DUC
          22 0 05645              AJP   0 /+2
05644     75 0 05555              SLJ   0 TEST1
          50 0 00000              ENI   0 0
05645     10 0 00000              ENA   0 0
          20 1 06040              STA   1 ICOUNT+9D
05646     72 1 06027              RAO   1 ICOUNT
          75 0 05555              SLJ   0 TEST1
05647     64 0 06100   INV2       EQS   0 DUC
          75 0 05651              SLJ   0 INV3
05650     50 1 00001              ENI   1 1
          75 0 05635              SLJ   0 INCD
05651     64 0 06077   INV3       EQS   0 TRIO
          75 0 05653              SLJ   0 INV4
05652     50 1 00002              ENI   1 2
          75 0 05635              SLJ   0 INCD
05653     64 0 06076   INV4       EQS   0 QUAD
          75 0 05671              SLJ   0 ERROR3
05654     50 1 00003              ENI   1 3
          75 0 05635              SLJ   0 INCD
05655     64 0 05237   NEXT2      EQS   0 CARDS36
          75 0 05657              SLJ   0 NEXT3
05656     50 1 00002              ENI   1 2
          75 0 05561              SLJ   0 ICCD
05657     64 0 05240   NEXT3      EQS   0 CARDS04
          75 0 05572              SLJ   0 TEST3
05660     50 1 00003              ENI   1 3
          75 0 05561              SLJ   0 ICCD
05661     64 0 05236   TEST5      EQS   0 CARD01
          75 0 05665              SLJ   0 ERROR1
05662     50 1 00004              ENI   1 4
          75 4 05705              SLJ   4 OUTPUT2
05663     75 4 05700              SLJ   4 INPUT2
          50 0 00000              ENI   0 0
05664     75 0 05641              SLJ   0 SER20
          50 0 00000              ENI   0 0
05665     12 0 06103   ERROR1     LDA   0 TAGE
          50 0 00000              ENI   0 0
05666     20 0 05271              STA   0 OUTBUF+2
          72 0 05253              RAO   0 FLAG
05667     75 0 05555              SLJ   0 TEST1
          50 0 00000              ENI   0 0
05670     12 0 06104   ERROR2     LDA   0 OUTE
          75 0 05666              SLJ   0 /-2
05671     12 0 06105   ERROR3     LDA   0 INE
          75 0 05666              SLJ   0 /-3
05672     75 0 00000   OUTCOUNT   SLJ   0 0
          50 6 00013              ENI   6 11D
05673     10 0 00000              ENA   0 0
          20 0 06062              STA   0 OUTCNT
05674     12 0 06110              LDA   0 CMASK
          16 0 06110              LDQ   0 CMASK
05675     46 6 05272              SBL   6 OUTBUF+3
          22 1 05677              AJP   1 /+2
05676     72 0 06062              RAO   0 OUTCNT
          50 0 00000              ENI   0 0
05677     55 6 05674              IJP   6 /-3
          75 0 05672              SLJ   0 OUTCOUNT
05700     75 0 00000   INPUT2     SLJ   0 0
          74 7 32000              EXF   7 32000
05701     10 0 05306              ENA   0 OUTBUF+15D
          61 0 00003              SAL   0 3
05702     74 0 32042              EXF   0 32042
          74 7 32000              EXF   7 32000
05703     74 3 05267              EXF   3 OUTBUF
```

```
          74 7 32000 .             EXF  7 32000
05704     75 0 05700               SLJ  0 INPUT2
          50 0 00000               ENI  0 0
05705     75 0 00000   OUTPUT2     SLJ  0 0
          74 7 42000               EXF  7 42000
05706     10 0 05306               ENA  0 OUTBUF+15D
          61 0 00004               SAL  0 4
05707     74 0 42032               EXF  0 42032
          74 7 42000               EXF  7 42000
05710     74 4 05267               EXF  4 OUTBUF
          74 7 42000               EXF  7 42000
05711     75 0 05705               SLJ  0 OUTPUT2
          50 0 00000               ENI  0 0
05712     75 0 00000   MSG         SLJ  0 0
          50 5 00000               ENI  5 0
05713     12 5 00000               LDA  5 0
          20 5 05270               STA  5 OUTBUF+1
05714     54 5 00000               ISK  5 0
          75 0 05713               SLJ  0 /-1
05715     75 4 05705               SLJ  4 OUTPUT2
          50 0 00000               ENI  0 0
05716     75 0 05712               SLJ  0 MSG
          50 0 00000               ENI  0 0
05717     75 0 00000   CLRBUF      SLJ  0 0
          12 0 06011               LDA  0 DBSP
05720     20 0 05267               STA  0 OUTBUF
          50 5 00015               ENI  5 13D
05721     12 0 05252               LDA  0 SPACE
          20 5 05270               STA  5 OUTBUF+1
05722     55 5 05721               IJP  5 /-1
          75 0 05717               SLJ  0 CLRBUF
05723     75 0 00000   ORCOUNT     SLJ  0 0
          10 0 00000               ENA  0 0
05724     20 0 06063               STA  0 ORCNT
          04 0 00000               ENQ  0 0
05725     16 6 05267               LDQ  6 OUTBUF
          50 4 00007               ENI  4 7
05726     07 0 00006               LLS  0 6
          50 0 00000               ENI  0 0
05727     64 0 06106               LQS  0 PLUS
          75 0 05731               SLJ  0 /+2
05730     72 0 06063               RAO  0 ORCNT
          50 0 00000               ENI  0 0
05731     10 0 00000               ENA  0 0
          55 4 05726               IJP  4 /-3
05732     55 6 05725               IJP  6 /-5
          72 0 06063               RAO  0 ORCNT
05733     75 0 05723               SLJ  0 ORCOUNT
          50 0 00000               ENI  0 0
05734     75 0 00000   OUTPIN      SLJ  0 0
          53 2 06067               LIL  2 WAIT
05735     16 0 06071               LDQ  0 SMASK
          44 0 05271               LDL  0 OUTBUF+2
05736     15 0 06071               SUB  0 SMASK
          22 0 05752               AJP  0 TYP3
05737     16 0 06111               LDQ  0 TMASK
          44 0 05271               LDL  0 OUTBUF+2
05740     22 1 05752               AJP  1 TYP3
          02 0 00001               QRS  0 1
05741     44 0 05271               LDL  0 OUTBUF+2
          22 1 05763               AJP  1 TYP2
05742     10 0 00001               ENA  0 1
          75 4 05771               SLJ  4 INPIN
05743     10 0 00014               ENA  0 12D
          50 0 00000               ENI  0 0
05744     05 0 00030   MID         ALS  0 24D
          70 2 16000               RAD  2 ALFA
05745     12 0 06070               LDA  0 FFFLG
          22 0 05750               AJP  0 /+3
05746     12 0 05455               LDA  0 BIT48
          20 2 16001               STA  2 ALFA+1
05747     10 0 00000               ENA  0 0
          20 0 06070               STA  0 FFFLG
```

```
05750    51 2 00022                    INI   2 22
         57 2 06067                    SIL   2 WAIT
05751    75 0 05734                    SLJ   0 OUTPIN
         50 0 00000                    ENI   0 0
05752    04 0 00077      TYP3          ENQ   0 77
         44 0 05270                    LDL   0 OUTBUF+1
05753    64 0 06114                    EQS   0 PTA
         75 0 05756                    SLJ   0 /+3
05754    10 0 00001                    ENA   0 1
         75 4 05771                    SLJ   4 INPIN
05755    10 0 00004                    ENA   0 4D
         75 0 05744                    SLJ   0 MID
05756    64 0 06115                    EQS   0 PTB
         75 0 05761                    SLJ   0 /+3
05757    10 0 00005                    ENA   0 5
         75 4 05771                    SLJ   4 INPIN
05760    10 0 00010                    ENA   0 8D
         75 0 05744                    SLJ   0 MID
05761    10 0 00011                    ENA   0 9D
         75 4 05771                    SLJ   4 INPIN
05762    75 0 05743                    SLJ   0 MID-1
         50 0 00000                    ENI   0 0
05763    04 0 00077      TYP2          ENQ   0 77
         44 0 05270                    LDL   0 OUTBUF+1
05764    64 0 06114                    EQS   0 PTA
         75 0 05767                    SLJ   0 /+3
05765    10 0 00001                    ENA   0 1
         75 4 05771                    SLJ   4 INPIN
05766    10 0 00006                    ENA   0 6
         75 0 05744                    SLJ   0 MID
05767    10 0 00007                    ENA   0 7
         75 4 05771                    SLJ   4 INPIN
05770    75 0 05743                    SLJ   0 MID-1
         50 0 00000                    ENI   0 0
05771    75 0 00000      INPIN         SLJ   0 0
         05 0 00036                    ALS   0 30D
05772    70 2 16000                    RAD   2 ALFA
         75 0 05771                    SLJ   0 INPIN
05773    75 0 00000      MAKEX         SLJ   0 0
         12 0 05301                    LDA   0 OUTBUF+10D
05774    20 0 06066                    STA   0 HOLD
         41 0 06112                    SCL   0 HIMASK
05775    07 0 00060                    LLS   0 48D
         12 0 05241                    LDA   0 TEMP
05776    75 4 06001                    SLJ   4 ENTER
         50 0 00000                    ENI   0 0
05777    12 0 05252                    LDA   0 SPACE
         20 0 05301                    STA   0 OUTBUF+10D
06000    75 0 05773                    SLJ   0 MAKEX
         50 0 00000                    ENI   0 0
06001    75 0 00000      ENTER         SLJ   0 0
         57 6 06065                    SIL   6 STORE
06002    53 6 06064                    LIL   6 COUNT
         20 6 10000                    STA   6 ARGUE
06003    21 6 13000                    STQ   6 VALUE
         50 0 00000                    ENI   0 0
06004    54 6 02777                    ISK   6 2777
         75 0 06006                    SLJ   0 /+2
06005    04 0 00000                    ENQ   0 0
         75 0 06007                    SLJ   0 /+2
06006    50 0 00000                    ENI   0 0
         57 6 06064                    SIL   6 COUNT
06007    53 6 06065                    LIL   6 STORE
         75 0 06001                    SLJ   0 ENTER
06010    01 2 02020      PAGEJ         BCD     /1
         20 2 02020
06011    12 2 02020      DBSP          BCD     /0
         20 2 02020
06012    00 0 00000      LNGTH1        DEC     7
         00 0 00007
06013    00 0 00000      LNGTH2        DEC     4
         00 0 00004
06014    00 0 00000      LNGTH3        DEC     5
```

```
                00 0 00005
06015           00 0 00000    RFR00     OCT      1
                00 0 00001
06016           00 0 00000    RFR01     OCT      12
                00 0 00012
06017           00 0 00000    RFR02     OCT      144
                00 0 00144
06020           00 0 00000    RFR03     OCT      1750
                00 0 01750
06021           20 2 02020    MASK      OCT      2020202020202000
                20 2 02000
06022           20 2 02020              OCT      2020202020200000
                20 2 00000
06023           20 2 02020              OCT      2020202020000000
                20 0 00000
06024           20 2 02020              OCT      2020202000000000
                00 0 00000
06025           00 0 00000    DOUB      DEC      9
                00 0 00011
06026           00 0 00000    TRIP      DEC      14
                00 0 00016
06027           00 0 00000    ICOUNT    BSS      18D
                00 0 00000
06051           00 0 00000    FCOUNT    BSS      9D
                00 0 00000
06062           00 0 00000    OUTCNT    BSS      1
                00 0 00000
06063           00 0 00000    ORCNT     BSS      1
                00 0 00000
06064           00 0 00000    COUNT     BSS      1
                00 0 00000
06065           00 0 00000    STORE     BSS      1
                00 0 00000
06066           00 0 00000    HOLD      BSS      1
                00 0 00000
06067           00 0 00000    WAIT      BSS      1
                00 0 00000
06070           00 0 00000    FEFLG     BSS      1
                00 0 00000
06071           00 0 02200    SMASK     OCT      220000000000
                00 0 00000
06072           20 2 00121    ATHIRD    OCT      2020012103202020
                03 2 02020
06073           20 2 00221    BTHIRD    OCT      2020022103202020
                03 2 02020
06074           20 2 00121    AHALF     OCT      2020012102202020
                02 2 02020
06075           00 0 00000    QUINT     OCT      5
                00 0 00005
06076           00 0 00000    QUAD      OCT      4
                00 0 00004
06077           00 0 00000    TRIO      OCT      3
                00 0 00003
06100           00 0 00000    DUO       OCT      2
                00 0 00002
06101           00 0 00000    OUTEND    OCT      7
                00 0 00007
06102           00 0 00000    SEXT      OCT      6
                00 0 00006
06103           00 0 00000    TAGE      OCT      54542020
                54 5 42020
06104           00 0 00054    OUTE      OCT      5454542020
                54 5 42020
06105           00 0 05454    INE       OCT      545454542020
                54 5 42020
06106           00 0 00000    PLUS      OCT      60
                00 0 00060
06107           00 0 00000    ZERO      OCT      12
                00 0 00012
06110           00 0 00000    CMASK     OCT      33000000
                33 0 00000
06111           00 0 00004    TMASK     OCT      400000000
                00 0 00000
```

```
06112     77 7 77777   HIMASK   OCT    7777777700000000
          00 0 00000
06113     00 0 00000   LOMASK   OCT    77777777
          77 7 77777
06114     00 0 00000   PTA      OCT    61
          00 0 00061
06115     00 0 00000   PTE      OCT    62
          00 0 00062
06116     20 2 02001   CARD     BCD    /    11
          01 2 02020
06117     20 2 02001            BCD    /    12
          02 2 02020
06120     20 2 02001            BCD    /    13
          03 2 02020
06121     20 2 02001            BCD    /    14
          04 2 02020
06122     20 2 02001            BCD    /    15
          05 2 02020
06123     20 2 02001            BCD    /    16
          06 2 02020
06124     20 2 02003            BCD    /    31
          01 2 02020
06125     20 2 02003            BCD    /    32
          02 2 02020
06126     20 2 02003            BCD    /    33
          03 2 02020
06127     20 2 02002            BCD    /    21
          01 2 02020
06130     20 2 02002            BCD    /    22
          02 2 02020
06131     20 2 02002            BCD    /    23
          03 2 02020
06132     20 2 02002            BCD    /    24
          04 2 02020
06133     20 2 02012            BCD    /    01
          01 2 02020
06134     20 2 02006            BCD    /    61
          01 2 02020
06135     20 2 02006            BCD    /    62
          02 2 02020
06136     20 2 02203            BCD    /   S36
          06 2 02020
06137     20 2 02212            BCD    /   S04
          04 2 02020
06140     24 2 02220   HEAD1    BCD    /U S NAVA
          45 6 12561
06141     43 2 04746            BCD    /L POST G
          22 2 32067
06142     51 6 16424            BCD    /RADUATE
          61 2 36520
06143     22 6 37046            BCD    /SCHOOL
          46 4 32020
06144     20 2 06461            BCD    /  DATA P
          23 6 12047
06145     51 4 66365            BCD    /ROCESSIN
          22 2 27145
06146     67 2 04361            BCD    /G LABORA
          62 4 65161
06147     23 4 65130            BCD    /TORY
          20 2 02020
06150     20 2 02020   HEAD2    BCD    /
          20 2 02020
06151     63 4 64447            BCD    /COMPILAT
          71 4 36123
06152     71 4 64520            BCD    /ION OF C
          46 6 62063
06153     61 5 16420            BCD    /ARD ASSI
          61 2 22271
06154     67 4 54465            BCD    /GNMENTS
          45 2 32220
06155     20 2 02020   HEAD3    BCD    /
          20 2 02020
06156     63 6 15164            BCD    /CARD TYP
```

```
        20 2 33047
06157   65 2 02020                    BCD     /F
        20 2 02020
06160   20 2 02020                    BCD     /
        20 2 02020
06161   45 2 44462                    BCD     /NUMBER O
        65 5 12046
06162   66 2 06361                    BCD     /F CARDS
        51 6 42220
06163   50 1 00000      PASS4         ENI     1 0
        50 2 00000                    ENI     2 0
06164   50 3 00000                    ENI     3 0
        50 4 00000                    ENI     4 0
06165   50 6 00002                    ENI     6 2
        10 0 00000                    ENA     0 0
06166   20 0 06027                    STA     0 ICOUNT
        20 0 06067                    STA     0 WAIT
06167   20 0 06066                    STA     0 HOLD
        75 4 05202                    SLJ     4 FILL
06170   12 0 06010                    LDA     0 PAGEJ
        20 0 05267                    STA     0 OUTBUF
06171   75 4 05705                    SLJ     4 OUTPUT2
        50 0 00000                    ENI     0 0
06172   75 4 05717                    SLJ     4 CLRBUF
        50 0 00000                    ENI     0 0
06173   10 0 06140                    ENA     0 HEAD1
        60 0 05713                    SAU     0 MSG+1
06174   12 0 06012                    LDA     0 LNGTH1
        60 0 05714                    SAU     0 MSG+2
06175   75 4 05712                    SLJ     4 MSG
        50 0 00000                    ENI     0 0
06176   75 4 05717                    SLJ     4 CLRBUF
        50 0 00000                    ENI     0 0
06177   10 0 06560                    ENA     0 HEAD4
        60 0 05713                    SAU     0 MSG+1
06200   12 0 06556                    LDA     0 LNGTH4
        60 0 05714                    SAU     0 MSG+2
06201   75 4 05712                    SLJ     4 MSG
        50 0 00000                    ENI     0 0
06202   75 0 06206                    SLJ     0 ONLY
        50 0 00000                    ENI     0 0
06203   75 4 05202      NXTP          SLJ     4 FILL
        50 0 00000                    ENI     0 0
06204   12 0 06010                    LDA     0 PAGEJ
        20 0 05267                    STA     0 OUTBUF
06205   75 4 05705                    SLJ     4 OUTPUT2
        50 0 00000                    ENI     0 0
06206   75 4 05717      ONLY          SLJ     4 CLRBUF
        50 0 00000                    ENI     0 0
06207   10 0 06565                    ENA     0 HEAD5
        60 0 05713                    SAU     0 MSG+1
06210   12 0 06557                    LDA     0 LNGTH5
        60 0 05714                    SAU     0 MSG+2
06211   75 4 05712                    SLJ     4 MSG
        50 0 00000                    ENI     0 0
06212   75 4 05717      WLINE         SLJ     4 CLRBUF
        50 0 00000                    ENI     0 0
06213   75 4 06223                    SLJ     4 GET
        50 0 00000                    ENI     0 0
06214   75 4 05705                    SLJ     4 OUTPUT2
        50 0 00000                    ENI     0 0
06215   12 0 05277                    LDA     0 OUTBUF+80
        41 0 05252                    SCL     0 SPACE
06216   22 1 06221                    AJP     1 /+3
        50 0 00000                    ENI     0 0
06217   74 0 42003                    EXF     0 42003
        74 7 42000                    EXF     7 42000
06220   74 0 42005                    EXF     0 42005
        76 0 05000                    SLS     0 5000
06221   54 6 00043                    ISK     6 35D
        75 0 06212                    SLJ     0 WLINE
06222   75 0 06203                    SLJ     0 NXTP
        50 0 00000                    ENI     0 0
```

```
06223     75 0 00000   .GET     SLJ   0 0
          10 2 00000            ENA   2 0
06224     22 1 06264            AJP   1 PREP
          12 0 06027            LDA   0 ICOUNT
06225     22 1 06321            AJP   1 UDAT
          12 3 16000            LDA   3 ALFA
06226     01 0 00036            ARS   0 30D
          20 0 06611            STA   0 PINNI
06227     10 0 00001            ENA   0 1
          20 0 06027            STA   0 ICOUNT
06230     51 1 00001   GOT      INI   1 1
          16 0 06113            LDQ   0 LCMASK
06231     44 1 16000            LDL   1 ALFA
          20 2 06603            STA   2 AND
06232     36 1 16001            SSK   1 ALFA+1
          75 0 06235            SLJ   0 PICK
06233     22 0 06230            AJP   0 GOT
          51 2 00001            INI   2 1
06234     75 0 06240            SLJ   0 COMPUT
          50 0 00000            ENI   0 0
06235     22 0 06237   PICK     AJP   0 /+2
          51 2 00001            INI   2 1
06236     75 0 06230            SLJ   0 GOT
          50 0 00000            ENI   0 0
06237     10 0 00000            ENA   0 0
          20 0 06027            STA   0 ICOUNT
06240     57 2 06066   COMPUT   SIL   2 HOLD
          10 2 00000            ENA   2 0
06241     22 0 06322            AJP   0 LOOK
          16 0 06113            LDQ   0 LCMASK
06242     44 3 16000            LDL   3 ALFA
          20 0 06602            STA   0 IAND
06243     55 2 06244            IJP   2 /+1
          75 0 06250            SLJ   0 BAT
06244     12 2 06603            LDA   2 AND
          75 4 06504            SLJ   4 SEARCHI
06245     50 0 00000            ENI   0 0
          02 0 00006            QRS   0 6
06246     21 2 06621            STQ   2 LOCNT
          75 4 06511            SLJ   4 DECOUT
06247     20 2 06612            STA   2 PINNO
          75 0 06243            SLJ   0 /-4
06250     16 0 06113   BAT      LDQ   0 LCMASK
          44 3 16000            LDL   3 ALFA
06251     75 4 06504            SLJ   4 SEARCHI
          50 0 00000            ENI   0 0
06252     02 0 00006            QRS   0 6
          21 0 06620            STQ   0 OLOC
06253     12 0 06611            LDA   0 PINNI
          11 0 00001            INA   0 1
06254     05 0 00036            ALS   0 30D
          17 0 06743            LQC   0 IMASK
06255     43 3 16000            SSU   3 ALFA
          20 3 16000            STA   3 ALFA
06256     50 0 00000            ENI   0 0
          04 0 00000            ENQ   0 0
06257     12 0 06747            LDA   0 INDIC
          20 0 05270            STA   0 OUTPUT+1
06260     53 2 06066            LIL   2 HOLD
          75 4 06327            SLJ   4 BEST
06261     12 0 06027            LDA   0 ICOUNT
          22 1 06264            AJP   1 PREP
06262     51 3 00022            INI   3 22
          56 3 06263            SIU   3 /+1
06263     50 1 00000            ENI   1 0
          50 0 00000            ENI   0 0
06264     51 2 77776   PREP     INI   2 -1
          57 6 05311            SIL   6 BETA
06265     04 0 00000            ENQ   0 0
          12 2 06717            LDA   2 TABLE
06266     07 0 00006            LLS   0 6
          20 0 05246            STA   0 TEMP+5
06267     21 0 05245            STQ   0 TEMP+4
```

```
         53 6 05245             LIL  6 TEMP+4
06270    12 6 06611             LDA  6 PINNI
         22 0 06275             AJP  0 /+5
06271    75 4 06526             SLJ  4 CNVT
         50 0 00000             ENI  0 0
06272    03 0 00022             LRS  0 18D
         12 6 06620             LDA  6 OLOC
06273    14 0 06737             ADD  0 PRMSK
         07 0 00022             LLS  0 18D
06274    75 0 06276             SLJ  0 /+2
         50 0 00000             ENI  0 0
06275    12 6 06602             LDA  6 IAND
         14 0 06740             ADD  0 UPSPA
06276    20 0 05273             STA  0 OUTBUF+4
         50 0 00000             ENI  0 0
06277    12 6 06602             LDA  6 IAND
         14 0 06741             ADD  0 TOSPA
06300    20 0 05277             STA  0 OUTBUF+8D
         12 0 05246             LDA  0 TEMP+5
06301    04 0 00000             ENQ  0 0
         07 0 00006             LLS  0 6
06302    21 0 05245             STQ  0 TEMP+4
         53 6 05245             LIL  6 TEMP+4
06303    12 6 06611             LDA  6 PINNI
         22 0 06310             AJP  0 /+5
06304    75 4 06526             SLJ  4 CNVT
         50 0 00000             ENI  0 0
06305    03 0 00022             LRS  0 18D
         12 6 06620             LDA  6 OLOC
06306    14 0 06737             ADD  0 PRMSK
         07 0 00022             LLS  0 18D
06307    75 0 06311             SLJ  0 /+2
         50 0 00000             ENI  0 0
06310    12 6 06602             LDA  6 IAND
         14 0 06740             ADD  0 UPSPA
06311    20 0 05271             STA  0 OUTBUF+2
         50 0 00000             ENI  0 0
06312    12 6 06602             LDA  6 IAND
         14 0 06740             ADD  0 UPSPA
06313    05 0 00014             ALS  0 12D
         20 0 05276             STA  0 OUTBUF+7
06314    16 0 06113             LDQ  0 LOMASK
         44 2 06717             LDL  2 TABLE
06315    75 4 06476             SLJ  4 WIRE
         50 0 00000             ENI  0 0
06316    20 0 05302             STA  0 OUTBUF+11D
         12 0 06601             LDA  0 INCRCS
06317    20 0 05303             STA  0 OUTBUF+12D
         53 6 05311             LIL  6 BETA
06320    75 0 06223             SLJ  0 GET
         50 0 00000             ENI  0 0
06321    72 0 06611     UDAT    RAO  0 PINNI
         75 0 06230             SLJ  0 GOT
06322    12 3 16000     LOOK    LDA  3 ALFA
         22 0 06223             AJP  0 GET
06323    12 3 16001             LDA  3 ALFA+1
         22 1 06325             AJP  1 /+2
06324    12 0 07227             LDA  0 CLOCK
         20 0 05277             STA  0 OUTBUF+8D
06325    51 3 00022             INI  3 22
         56 3 06326             SIU  3 /+1
06326    50 1 00000             ENI  1 0
         75 0 06223             SLJ  0 GET
06327    75 0 00000     BEST    SLJ  0 0
         57 6 06065             SIL  6 STORE
06330    10 0 00000             ENA  0 0
         50 6 00107             ENI  6 71D
06331    20 6 06627             STA  6 SINK
         55 6 06331             IJP  6 /
06332    20 0 05253             STA  0 FLAG
         75 4 06401             SLJ  4 POSITS
06333    55 2 06332             IJP  2 /-1
         12 0 06066             LDA  0 HOLD
```

```
06334   60 0 06451                SAU  0 DIAG+11D
        11 0 77776                INA  0 -1
06335   60 0 06452                SAU  0 DIAG+12D
        75 4 06436                SLJ  4 DIAG
06336   12 0 06066                LDA  0 HOLD
        57 2 05245                SIL  2 TEMP+4
06337   11 0 77776                INA  0 -1
        60 0 06376                SAU  0 ACCEPT+3
06340   16 0 07224   MAINL        LDQ  0 BLOT
        51 2 77776                INI  2 -1
06341   50 0 00000                ENI  0 0
        44 2 06654                LDL  2 CHAIR
06342   22 1 06343                AJP  1 /+1
        55 2 06341                IJP  2 /-1
06343   04 6 00000                ENQ  6 0
        23 1 06351                QJP  1 EARLY
06344   07 0 00006                LLS  0 6
        05 0 00006                ALS  0 6
06345   20 0 06735                STA  0 END1
        20 0 06726                STA  0 SUBTRE
06346   21 0 06736                STQ  0 END1+1
        21 0 06727                STQ  0 SUBTRE+1
06347   50 4 00002                ENI  4 2
        57 4 06067                SIL  4 WAIT
06350   75 0 06373                SLJ  0 ACCEPT
        50 0 00000                ENI  0 0
06351   04 0 00000   EARLY        ENQ  0 0
        07 0 00006                LLS  0 6
06352   05 0 00006                ALS  0 6
        50 0 00000                ENI  0 0
06353   64 4 06735   DOG          EQS  4 END1
        75 0 06361                SLJ  0 RAT
06354   57 4 05247                SIL  4 TEMP+6
        50 0 00000                ENI  0 0
06355   07 0 00060                LLS  0 48D
        53 4 06067                LIL  4 WAIT
06356   64 4 06726                EQS  4 SUBTRE
        75 0 06367                SLJ  0 WEDO
06357   10 0 00000                ENA  0 0
        20 2 06654                STA  2 CHAIR
06360   20 0 05253                STA  0 FLAG
        75 0 06340                SLJ  0 MAINL
06361   53 4 05253   RAT          LIL  4 FLAG
        55 4 06365                IJP  4 SKIP
06362   07 0 00060                LLS  0 48D
        50 4 00001                ENI  4 1
06363   57 4 05253                SIL  4 FLAG
        50 4 00002                ENI  4 2
06364   75 0 06353                SLJ  0 DOG
        50 0 00000                ENI  0 0
06365   57 4 05253   SKIP         SIL  4 FLAG
        50 4 00002                ENI  4 2
06366   75 0 06340                SLJ  0 MAINL
        50 0 00000                ENI  0 0
06367   53 4 06067   WEDO         LIL  4 WAIT
        20 4 06726                STA  4 SUBTRE
06370   53 4 05247                LIL  4 TEMP+6
        20 4 06735                STA  4 END1
06371   72 0 06067                RAO  0 WAIT
        10 0 00000                ENA  0 0
06372   20 0 05253                STA  0 FLAG
        50 0 00000                ENI  0 0
06373   12 2 06654   ACCEPT       LDA  2 CHAIR
        20 6 06717                STA  6 TABLE
06374   10 0 00000                ENA  0 0
        20 2 06654                STA  2 CHAIR
06375   50 4 00002                ENI  4 2
        53 2 05245                LIL  2 TEMP+4
06376   54 6 00000                ISK  6 0
        75 0 06340                SLJ  0 MAINL
06377   53 2 06066                LIL  2 HOLD
        53 6 06065                LIL  6 STORE
06400   75 0 06327                SLJ  0 BEST
```

```
        50 0 00000          ENI 0 0
06401   75 0 00000  POSITS  SLJ 0 0
        04 0 00077          ENQ 0 77
06402   44 2 06620          LDL 2 OLOC
        22 0 06434          AJP 0 NULOT
06403   64 0 06107          EQS 0 ZERO
        75 0 06405          SLJ 0 /+2
06404   10 0 00000          ENA 0 0
        50 0 00000          ENI 0 0
06405   20 0 05246          STA 0 TEMP+5
        06 0 00006          QLS 0 6
06406   44 2 06620          LDL 2 OLCC
        01 0 00006          ARS 0 6
06407   64 0 06107          EQS 0 ZERO
        75 0 06411          SLJ 0 /+2
06410   10 0 00000          ENA 0 0
        50 0 00000          ENI 0 0
06411   24 0 06107          MUI 0 ZERO
        70 0 05246          RAD 0 TEMP+5
06412   24 0 06746          MUI 0 DCOL
        20 2 06701          STA 2 HOR
06413   16 0 07221          LDQ 0 GLOP
        44 2 06620          LDL 2 OLCC
06414   22 1 06416          AJP 1 /+2
        10 0 00011          ENA 0 9D
06415   20 0 05246          STA 0 TEMP+5
        75 0 06417          SLJ 0 /+2
06416   10 0 00000          ENA 0 0
        20 0 05246          STA 0 TEMP+5
06417   16 0 07222          LDQ 0 GLUM
        44 2 06620          LDL 2 OLCC
06420   22 0 06425          AJP 0 /+5
        10 0 00007          ENA 0 7
06421   70 0 05246          RAD 0 TEMP+5
        04 0 10000          ENQ 0 10000
06422   44 2 06620          LDL 2 OLCC
        22 0 06424          AJP 0 /+2
06423   10 0 00002          ENA 0 2
        75 0 06427          SLJ 0 /+4
06424   10 0 00001          ENA 0 1
        75 0 06427          SLJ 0 /+3
06425   16 0 07223          LDQ 0 BLUB
        44 2 06620          LDL 2 OLCC
06426   01 0 00014          ARS 0 12D
        50 0 00000          ENI 0 0
06427   70 0 05246          RAD 0 TEMP+5
        24 0 06744          MUI 0 DROW
06430   20 0 05246          STA 0 TEMP+5
        12 2 06611          LDA 2 PINNI
06431   24 0 06745          MUI 0 DPIN
        14 0 05246          ADD 0 TEMP+5
06432   20 2 06710          STA 2 VER
        10 0 00000          ENA 0 0
06433   75 0 06401          SLJ 0 POSITS
        50 0 00000          ENI 0 0
06434   20 2 06701  NULOT   STA 2 HOR
        20 2 06710          STA 2 VER
06435   10 0 00000          ENA 0 0
        75 0 06401          SLJ 0 POSITS
06436   75 0 00000  DIAG    SLJ 0 0
        57 3 05246          SIL 3 TEMP+5
06437   50 3 00000          ENI 3 0
        50 6 00001          ENI 6 1
06440   12 6 06701          LDA 6 HOR
        15 2 06701          SUB 2 HOR
06441   20 0 05245          STA 0 TEMP+4
        24 0 05245          MUI 0 TEMP+4
06442   20 0 05245          STA 0 TEMP+4
        12 6 06710          LDA 6 VER
06443   15 2 06710          SUB 2 VER
        20 0 05247          STA 0 TEMP+6
06444   24 0 05247          MUI 0 TEMP+6
        70 0 05245          RAD 0 TEMP+4
```

```
06445   10 6 00000            ENA  6 0
        05 0 00006            ALS  0 6
06446   11 2 00000            INA  2 0
        05 0 00044            ALS  0 36D
06447   14 0 05245            ADD  0 TEMP+4
        20 3 06627            STA  3 SINK
06450   51 3 00001            INI  3 1
        50 0 00000            ENI  0 0
06451   54 6 00000            ISK  6 0
        75 0 06440            SLJ  0 DIAG+2
06452   54 2 00000            ISK  2 0
        75 0 06454            SLJ  0 /+2
06453   51 3 77776            INI  3 -1
        75 0 06456            SLJ  0 ORDER
06454   57 2 05245            SIL  2 TEMP+4
        53 6 05245            LIL  6 TEMP+4
06455   51 6 00001            INI  6 1
        75 0 06440            SLJ  0 DIAG+2
06456   57 3 05245   ORDER    SIL  3 TEMP+4
        72 0 05245            RAO  0 TEMP+4
06457   16 0 07223            LDQ  0 BLAM
        10 3 00000            ENA  3 0
06460   11 0 06627            INA  0 SINK
        61 0 06462            SAL  0 /+2
06461   60 0 06471            SAU  0 VARI
        50 0 00000            ENI  0 0
06462   53 6 05245            LIL  6 TEMP+4
        44 0 00000            LDL  0 0
06463   67 6 06627            MTH  6 SINK
        75 0 06467            SLJ  0 /+4
06464   57 6 07226            SIL  6 GOFER
        10 0 06627            ENA  0 SINK
06465   14 0 07226            ADD  0 GOFER
        60 0 06471            SAU  0 VARI
06466   44 6 06627            LDL  6 SINK
        75 0 06463            SLJ  0 /-3
06467   52 5 06471            LIU  5 VARI
        12 5 00000            LDA  5 0
06470   20 2 06654            STA  2 CHAIR
        10 0 00000            ENA  0 0
06471   20 0 00000   VARI     STA  0 0
        51 2 00001            INI  2 1
06472   55 3 06474            IJP  3 LAMP
        53 3 05246            LIL  3 TEMP+5
06473   75 0 06436            SLJ  0 DIAG
        50 0 00000            ENI  0 0
06474   53 5 06462   LAMP     LIL  5 ORDER+4
        56 5 06471            SIU  5 VARI
06475   75 0 06462            SLJ  0 ORDER+4
        50 0 00000            ENI  0 0
06476   75 0 00000   WIRE     SLJ  0 0
        50 0 00000            ENI  0 0
06477   57 6 06065            SIL  6 STORE
        50 6 00124            ENI  6 84D
06500   65 6 07074            THS  6 APPX
        75 0 06502            SLJ  0 /+2
06501   12 6 06750            LDA  6 TYPE
        75 0 06503            SLJ  0 /+2
06502   12 0 07220            LDA  0 MAX
        50 0 00000            ENI  0 0
06503   53 6 06065            LIL  6 STORE
        75 0 06476            SLJ  0 WIRE
06504   75 0 00000   SEARCH1  SLJ  0 0
        04 0 00000            ENQ  0 0
06505   57 6 06065            SIL  6 STORE
        53 6 06064            LIL  6 COUNT
06506   64 6 10000            EQS  6 ARGUE
        75 0 06510            SLJ  0 /+2
06507   16 6 13000            LDQ  6 VALUE
        50 0 00000            ENI  0 0
06510   53 6 06065            LIL  6 STORE
        75 0 06504            SLJ  0 SEARCH1
06511   75 0 00000   DECOUT   SLJ  0 0
```

```
        57 6 06065              SIL   6 STORE
06512   53 6 05242              LIL   6 TEMP+1
        16 0 06113              LDQ   0 LOMASK
06513   66 6 16000              MEQ   6 ALFA
        75 0 06524              SLJ   0 /+9D
06514   16 0 06742              LDQ   0 OMASK
        44 6 16000              LDL   6 ALFA
06515   22 1 06517              AJP   1 /+2
        12 2 06603              LDA   2 AND
06516   16 0 06113              LDQ   0 LOMASK
        75 0 06513              SLJ   0 /-3
06517   01 0 00030              ARS   0 24D
        20 0 06067              STA   0 WAIT
06520   11 0 77776              INA   0 -1
        05 0 00030              ALS   0 24D
06521   17 0 06742              LQC   0 OMASK
        43 6 16000              SSU   6 ALFA
06522   20 6 16000              STA   6 ALFA
        12 0 06067              LDA   0 WAIT
06523   75 0 06525              SLJ   0 /+2
        50 0 00000              ENI   0 0
06524   10 0 00000              ENA   0 0
        50 0 00000              ENI   0 0
06525   53 6 06065              LIL   6 STORE
        75 0 06511              SLJ   0 DECOUT
06526   75 0 00000     CNVT     SLJ   0 0
        57 6 06065              SIL   6 STORE
06527   50 6 00011              ENI   6 9D
        04 0 00077              ENQ   0 77
06530   66 6 06542              MEQ   6 BACK
        75 0 06532              SLJ   0 /+2
06531   75 0 06537              SLJ   0 /+6
        50 0 00000              ENI   0 0
06532   15 0 06541              SUB   0 FORTN
        22 3 06534              AJP   3 /+2
06533   12 0 06555              LDA   0 BACK+11D
        75 0 06540              SLJ   0 RAW
06534   11 0 00001              INA   0 1
        22 3 06536              AJP   3 /+2
06535   12 0 06554              LDA   0 BACK+10D
        75 0 06540              SLJ   0 RAW
06536   12 0 06553              LDA   0 BACK+9D
        75 0 06540              SLJ   0 RAW
06537   12 6 06542              LDA   6 BACK
        50 0 00000              ENI   0 0
06540   53 6 06065     RAW      LIL   6 STORE
        75 0 06526              SLJ   0 CNVT
06541   00 0 00000     FORTN    OCT     14
        00 0 00014
06542   00 0 00000     BACK     OCT     401201
        00 4 01201
06543   00 0 00000              OCT     401202
        00 4 01202
06544   00 0 00000              OCT     401203
        00 4 01203
06545   00 0 00000              OCT     401204.
        00 4 01204
06546   00 0 00000              OCT     401205
        00 4 01205
06547   00 0 00000              OCT     401206
        00 4 01206
06550   00 0 00000              OCT     401207
        00 4 01207
06551   00 0 00000              OCT     401210
        00 4 01210
06552   00 0 00000              OCT     401211
        00 4 01211
06553   00 0 00000              OCT     400112
        00 4 00112
06554   00 0 00000              OCT     400101
        00 4 00101
06555   00 0 00000              OCT     400102
        00 4 00102
```

```
06556    00 0 00000   . LNGTH4    DEC     4
         00 0 00004
06557    00 0 00000     LNGTH5    DEC     11D
         00 0 00013
06560    20 2 02020     HEAD4     BCD     /
         20 2 02020
06561    71 4 52365               BCD     /INTER CA
         51 2 06361
06562    51 6 42026               BCD     /RD WIRIN
         71 5 17149
06563    67 2 02361               BCD     /G TABULA
         62 2 44361
06564    23 7 14645               BCD     /TION
         20 2 02020
06565    20 2 02020     HEAD5     BCD     /
         20 2 02020
06566    20 2 04651               BCD     /  ORIGIN
         71 6 77145
06567    20 2 02020               BCD     /
         20 2 02020
06570    64 6 52223               BCD     /DESTINAT
         71 4 56123
06571    71 4 64520               BCD     /ION
         20 2 02020
06572    20 2 02020               BCD     /
         20 2 02020
06573    20 2 02064               BCD     /   DESIG
         65 2 27167
06574    45 6 12371               BCD     /NATIONS
         46 4 52220
06575    20 2 02020               BCD     /
         20 2 02020
06576    20 2 02020               BCD     /
         20 2 02020
06577    26 7 15165               BCD     /WIRE LEN
         20 4 36545
06600    67 2 37020               BCD     /GTH
         20 2 02020
06601    71 4 56370     INCHES    BCD     /INCHES
         65 2 22020
06602    00 0 00000     IAND      BSS     1
         00 0 00000
06603    00 0 00000     AND       BSS     6
         00 0 00000
06611    00 0 00000     PINNI     BSS     1
         00 0 00000
06612    00 0 00000     PINNO     BSS     6
         00 0 00000
06620    00 0 00000     OLOC      BSS     1
         00 0 00000
06621    00 0 00000     LOCAT     BSS     6
         00 0 00000
06627    00 0 00000     SINK      BSS     21D
         00 0 00000
06654    00 0 00000     CHAIR     BSS     21D
         00 0 00000
06701    00 0 00000     HOR       BSS     7
         00 0 00000
06710    00 0 00000     VER       BSS     7
         00 0 00000
06717    00 0 00000     TABLE     BSS     7
         00 0 00000
06726    00 0 00000     SUBTRE    BSS     7
         00 0 00000
06735    00 0 00000     END1      BSS     2
         00 0 00000
06737    00 0 00020     PRMSK     OCT     2020000000
         20 0 00000
06740    20 2 02020     UPSPA     OCT     202020200000000
         00 0 00000
06741    23 4 62020     TOSPA     OCT     234620200000000
         00 0 00000
06742    00 0 00077     OMASK     OCT     7700000000
```

```
                00 0 00000
06743           00 0 07700   IMASK   OCT   770000000000
                00 0 00000
06744           00 0 00000   DROW    DEC   38
                00 0 00046
06745           00 0 00000   DPIN    DEC   2
                00 0 00002
06746           00 0 00000   DCOL    DEC   5
                00 0 00005
06747           20 2 02054   INDIG   BCD   /    *
                20 2 02020
06750           04 0 32020   TYPE    BCD   /43
                20 2 02020
06751           04 0 22001           BCD   /42 1/2
                21 0 22020
06752           04 0 22020           BCD   /42
                20 2 02020
06753           04 0 12001           BCD   /41 1/2
                21 0 22020
06754           04 0 12020           BCD   /41
                20 2 02020
06755           04 1 22001           BCD   /40 1/2
                21 0 22020
06756           04 1 22020           BCD   /40
                20 2 02020
06757           03 1 12001           BCD   /39 1/2
                21 0 22020
06760           03 1 12020           BCD   /39
                20 2 02020
06761           03 1 02001           BCD   /38 1/2
                21 0 22020
06762           03 1 02020           BCD   /38
                20 2 02020
06763           03 0 72001           BCD   /37 1/2
                21 0 22020
06764           03 0 72020           BCD   /37
                20 2 02020
06765           03 0 62001           BCD   /36 1/2
                21 0 22020
06766           03 0 62020           BCD   /36
                20 2 02020
06767           03 0 52001           BCD   /35 1/2
                21 0 22020
06770           03 0 52020           BCD   /35
                20 2 02020
06771           03 0 42001           BCD   /34 1/2
                21 0 22020
06772           03 0 42020           BCD   /34
                20 2 02020
06773           03 0 32001           BCD   /33 1/2
                21 0 22020
06774           03 0 32020           BCD   /33
                20 2 02020
06775           03 0 22001           BCD   /32 1/2
                21 0 22020
06776           03 0 22020           BCD   /32
                20 2 02020
06777           03 0 12001           BCD   /31 1/2
                21 0 22020
07000           03 0 12020           BCD   /31
                20 2 02020
07001           03 1 22001           BCD   /30 1/2
                21 0 22020
07002           03 1 22020           BCD   /30
                20 2 02020
07003           02 1 12001           BCD   /29 1/2
                21 0 22020
07004           02 1 12020           BCD   /29
                20 2 02020
07005           02 1 02001           BCD   /28 1/2
                21 0 22020
07006           02 1 02020           BCD   /28
                20 2 02020
```

```
07007      02 0 72001      BCD   /27 1/2
           21 0 22020
07010      02 0 72020      BCD   /27
           20 2 02020
07011      02 0 62001      BCD   /26 1/2
           21 0 22020
07012      02 0 62020      BCD   /26
           20 2 02020
07013      02 0 52001      BCD   /25 1/2
           21 0 22020
07014      02 0 52020      BCD   /25
           20 2 02020
07015      02 0 42001      BCD   /24 1/2
           21 0 22020
07016      02 0 42020      BCD   /24
           20 2 02020
07017      02 0 32001      BCD   /23 1/2
           21 0 22020
07020      02 0 32020      BCD   /23
           20 2 02020
07021      02 0 22001      BCD   /22 1/2
           21 0 22020
07022      02 0 22020      BCD   /22
           20 2 02020
07023      02 0 12001      BCD   /21 1/2
           21 0 22020
07024      02 0 12020      BCD   /21
           20 2 02020
07025      02 1 22001      BCD   /20 1/2
           21 0 22020
07026      02 1 22020      BCD   /20
           20 2 02020
07027      01 1 12001      BCD   /19 1/2
           21 0 22020
07030      01 1 12020      BCD   /19
           20 2 02020
07031      01 1 02001      BCD   /18 1/2
           21 0 22020
07032      01 1 02020      BCD   /18
           20 2 02020
07033      01 0 72001      BCD   /17 1/2
           21 0 22020
07034      01 0 72020      BCD   /17
           20 2 02020
07035      01 0 62001      BCD   /16 1/2
           21 0 22020
07036      01 0 62020      BCD   /16
           20 2 02020
07037      01 0 52001      BCD   /15 1/2
           21 0 22020
07040      01 0 52020      BCD   /15
           20 2 02020
07041      01 0 42001      BCD   /14 1/2
           21 0 22020
07042      01 0 42020      BCD   /14
           20 2 02020
07043      01 0 32001      BCD   /13 1/2
           21 0 22020
07044      01 0 32020      BCD   /13
           20 2 02020
07045      01 0 22001      BCD   /12 1/2
           21 0 22020
07046      01 0 22020      BCD   /12
           20 2 02020
07047      01 0 12001      BCD   /11 1/2
           21 0 22020
07050      01 0 12020      BCD   /11
           20 2 02020
07051      01 1 22001      BCD   /10 1/2
           21 0 22020
07052      01 1 22020      BCD   /10
           20 2 02020
07053      20 1 12001      BCD   / 9 1/2
```

```
          21 0 22020
07054     20 1 12020              BCD    / 9
          20 2 02020
07055     20 1 02001              BCD    / 8 1/2
          21 0 22020
07056     20 1 02020              BCD    / 8
          20 2 02020
07057     20 0 72001              BCD    / 7 1/2
          21 0 22020
07060     20 0 72020              BCD    / 7
          20 2 02020
07061     20 0 62001              BCD    / 6 1/2
          21 0 22020
07062     20 0 62020              BCD    / 6
          20 2 02020
07063     20 0 52001              BCD    / 5 1/2
          21 0 22020
07064     20 0 52020              BCD    / 5
          20 2 02020
07065     20 0 42001              BCD    / 4 1/2
          21 0 22020
07066     20 0 42020              BCD    / 4
          20 2 02020
07067     20 0 32001              BCD    / 3 1/2
          21 0 22020
07070     20 0 32020              BCD    / 3
          20 2 02020
07071     20 0 22001              BCD    / 2 1/2
          21 0 22020
07072     20 0 22020              BCD    / 2
          20 2 02020
07073     20 0 12001              BCD    / 1 1/2
          21 0 22020
07074     00 0 00000   APPX       DEC    284516
          01 0 53544
07075     00 0 00000              DEC    277782
          01 0 36426
07076     00 0 00000              DEC    271128
          01 0 21430
07077     00 0 00000              DEC    264556
          01 0 04554
07100     00 0 00000              DEC    258064
          00 7 70020
07101     00 0 00000              DEC    251653
          00 7 53405
07102     00 0 00000              DEC    245322
          00 7 37112
07103     00 0 00000              DEC    239072
          00 7 22740
07104     00 0 00000              DEC    232902
          00 7 06706
07105     00 0 00000              DEC    226814
          00 6 72776
07106     00 0 00000              DEC    220806
          00 6 57206
07107     00 0 00000              DEC    214879
          00 6 43537
07110     00 0 00000              DEC    209032
          00 6 30210
07111     00 0 00000              DEC    203266
          00 6 15002
07112     00 0 00000              DEC    197580
          00 6 01714
07113     00 0 00000              DEC    191975
          00 5 66747
07114     00 0 00000              DEC    186451
          00 5 54123
07115     00 0 00000              DEC    181008
          00 5 41420
07116     00 0 00000              DEC    175645
          00 5 27035
07117     00 0 00000              DEC    170363
          00 5 14573
```

```
07120      00 0 00000          DEC      165161
           00 5 02451
07121      00 0 00000          DEC      160040
           00 4 70450
07122      00 0 00000          DEC      155000
           00 4 56570
07123      00 0 00000          DEC      150040
           00 4 45030
07124      00 0 00000          DEC      145161
           00 4 33411
07125      00 0 00000          DEC      140363
           00 4 22113
07126      00 0 00000          DEC      135645
           00 4 10735
07127      00 0 00000          DEC      131008
           00 3 77700
07130      00 0 00000          DEC      126457
           00 3 66771
07131      00 0 00000          DEC      121976
           00 3 56170
07132      00 0 00000          DEC      117580
           00 3 45514
07133      00 0 00000          DEC      113266
           00 3 35162
07134      00 0 00000          DEC      109032
           00 3 24750
07135      00 0 00000          DEC      104879
           00 3 14657
07136      00 0 00000          DEC      100806
           00 3 04706
07137      00 0 00000          DEC      96814
           00 2 75056
07140      00 0 00000          DEC      92903
           00 2 65347
07141      00 0 00000          DEC      89072
           00 2 55760
07142      00 0 00000          DEC      85322
           00 2 46512
07143      00 0 00000          DEC      81653
           00 2 37565
07144      00 0 00000          DEC      78064
           00 2 30360
07145      00 0 00000          DEC      74556
           00 2 21474
07146      00 0 00000          DEC      71129
           00 2 12731
07147      00 0 00000          DEC      67782
           00 2 04306
07150      00 0 00000          DEC      64516
           00 1 76004
07151      00 0 00000          DEC      61331
           00 1 67623
07152      00 0 00000          DEC      58227
           00 1 61563
07153      00 0 00000          DEC      55202
           00 1 53642
07154      00 0 00000          DEC      52258
           00 1 46042
07155      00 0 00000          DEC      49395
           00 1 40363
07156      00 0 00000          DEC      46613
           00 1 33025
07157      00 0 00000          DEC      43911
           00 1 25607
07160      00 0 00000          DEC      41290
           00 1 20512
07161      00 0 00000          DEC      38750
           00 1 13536
07162      00 0 00000          DEC      36290
           00 1 06702
07163      00 0 00000          DEC      33911
           00 1 02167
07164      00 0 00000          DEC      31613
```

```
               00 0 75575
07165          00 0 00C00                 DEC     29395
               00 0 71323
07166          00 0 00C00                 DEC     27258
               00 0 65172
07167          00 0 00C00                 DEC     25202
               00 0 61162
07170          00 0 C0C00                 DEC     23226
               00 0 55272
07171          00 0 00000                 DEC     21331
               00 0 51523
07172          00 0 00C00                 DEC     19516
               00 0 46074
07173          00 0 00C00                 DEC     17782
               00 0 42566
07174          00 0 00C00                 DEC     16129
               00 0 37401
07175          00 0 00C00                 DEC     14556
               00 0 34334
07176          00 0 00C00                 DEC     13064
               00 0 31410
07177          00 0 00C00                 DEC     11653
               00 0 26605
07200          00 0 00C00                 DEC     10323
               00 0 24123
07201          00 0 00C00                 DEC     9073
               00 0 21561
07202          00 0 00C00                 DEC     7903
               00 0 17337
07203          00 0 00C00                 DEC     6815
               00 0 15237
07204          00 0 00C00                 DEC     5806
               00 0 13256
07205          00 0 00C00                 DEC     4879
               00 0 11417
07206          00 0 00C00                 DEC     4032
               00 0 07700
07207          00 0 00C00                 DEC     3266
               00 0 06302
07210          00 0 00C00                 DEC     2581
               00 0 05025
07211          00 0 00C00                 DEC     1976
               00 0 03670
07212          00 0 00C00                 DEC     1452
               00 0 02654
07213          00 0 00C00                 DEC     1008
               00 0 01760
07214          00 0 00C00                 DEC     645
               00 0 01205
07215          00 0 00C00                 DEC     363
               00 0 00553
07216          00 0 00C00                 DEC     137
               00 0 00211
07217          00 0 00C00                 DEC     70
               00 0 00106
07220          04 0 36020     MAX         BCD     /43+
               20 2 02020
07221          00 0 00C00     GLOP        OCT     200000
               00 2 00C00
07222          00 0 00C00     GLUM        OCT     100000
               00 1 00C00
07223          00 0 07777     BLAM        OCT     000077777777777
               77 7 77777
07224          77 7 70C00     BLOT        OCT     777700000000000
               00 0 00000
07225          00 0 00C00     BLUB        OCT     70000
               00 0 70C00
07226          00 0 00C0C     GOFER       OCT     0
               00 0 00C00
07227          20 2 02063     CLOCK       BCD     /   CLOCK
               43 4 66342
                              ARGLE       EQU     10000
                              VALLE       EQU     13000
```

```
.ALFA          EQU       16000
               END
```

CHAPTER II

CONTROL DATA CORPORATION INPUT AND OUTPUT CODING AND CONTROL LINES

A. 1604

1. Coding

The external function instruction (74) acts in three different modes to give (a) activation of a channel; (b) sensing of a condition at an external equipment or (c) selecting an external equipment to communicate with the computer.

The channel activate sub-instructions 74.1 through 74.6 are interpreted as follows:

74	1 thru 6	Base Execution Address
6 bit operation code	3 bit index (channel) designator	15 bits which specifies the initial address for data storage in buffering operation

The sense sub-instruction 74.7 is interpreted as follows:

74	7	1 thru 7	1 thru 7	
sense		3 bit channel selection code	3 bits external equipment code	9 bits condition code which specifies operation being sensed

NOTE: If the sensed condition is met, a full exit from the word is performed. If the sensed condition is not met, a half exit from the word is performed.

The select sub-instruction 74.0 is interpreted as follows:

74	0	1 thru 7		
6 bit operation code	3 bit index	3 bits channel selection code	[illegible] bits external equipment code	9 bits condition code which specifies operation being selected
Select				

2. <u>Data and Control Lines</u>

Input equipment to computer

input data (48 lines)		Comprise two complete cables and two lines of a third cable of a buffer or transfer cable group
Input data ready (1 line)	Function:	Indicates equipment input register contains information which computer may sample.
	Operation:	Turned off by input data resume from computer. (Computer re-sync circuitry orients itself about leading edge of ready signal; auxiliary scanner is stopped and input word is passed to computer.)

Computer to Input Equipment

Input data resume (1 line)	Function:	Indicates to equipment that computer has accepted input word.
	Operation:	Turned off by input data ready; turned on when computer has accepted and stored input word.

Computer to Output Equipment

Output (48 lines)		Comprise two complete cables and two lines of a third cable of a buffer or transfer cable group.
Output data ready (1 line)	Function:	Accompanies output data from computer.
	Operation:	Turned on when computer has word of information ready for equipment; off by resume from equipment.

Output Equipment to Computer

Output data resume (1 line)	Function:	Indicates that equipment has accepted word.
	Operation:	Turned on when equipment has accepted word. (Computer resync circuitry orients itself about the trailing edge of resume; when signal drops auxiliary scanner stops and another word is exchanged. Computer prepares a word for exchange while output data resume signal is up.)

Computer to External Equipment

External function (12 lines)	Function:	Carries external function (EF) codes to select or sense a condition within the equipment
	Operation:	Lines continuously monitored by all equipment. Appropriate function or sense ready alerts equipment on a

in parallel to single EF code on lines.

External Master Function: Clears all equipment on all channels.
clear (1 line) Operation: Occurs when clear switch at console is in up position.

External Equipment to Computer

Sense response Function: Indicates equipment's reply to sense code.
Operation: ON indicates presence of condition specified by sense code; OFF indicates absence of condition.

Interrupt (1 line) Operation: External equipment or internal computer control sends signal when a condition arises that was previously selected by a 74.4.

Computer to Input Equipment

Input function ready (1 line) Function: Accompanies EF select code
Operation: Turned on by instruction 74.6. Causes input equipment to translate EF code.

Input sense ready (1 line) Function: Accompanies EF sense Code
Operation: Turned on by instruction 74.7. Causes input equipment to translate EF code and send response back to computer.

Input buffer active (1 line) Function: Indicates computer is prepared to receive a block of data.
Operation: Turned on when input buffer channel

		is activated by instruction 74.1, 74.3 or 74.5. Remains on until final word of block is entered in storage.

Computer to Output Equipment

Output Function Ready (1 line)	Function:	Accompanies EF select code.
	Operation:	Turned on by instruction 74.0. Causes output equipment to translate EF code.
Output Sense Ready (1 line)	Function:	Accompanies EF sense code.
	Operation:	Turned on by instruction 74.7. Causes output equipment to translate EF code and send response back to computer.
Output Buffer Active (1 line)	Function:	Indicates computer is prepared to transmit a block of data.
	Operation:	Turned on when output buffer channel is activated by instructions 74.2, 74.4, or 74.6. Remains on until final word of block is transmitted to output equipment.

B. 160

1. Coding

The computer controls the operation of its external equipment by issuing 12 bit function codes. This process, initiated by the external function (75) instruction, places a designated 12-bit code on the output lines and activates the Function Ready signal. Each external equipment receives the data, but only the equipment recognizing it responds to it by sending back a function resume signal.

[illegible] is built into the 160, but one of the 12-bit function codes may be used [illegible] a status request from the external equipment. The equipment must be designed to place a 12-bit status response code on the input cable. The 160 must then process this response through an input instruction INP (76) which will bring the 12 bits into the "A" register. The status response must be a one out of twelve response for each condition as more than one condition may exist. This allows for only twelve possible conditions for sensing to be designed into any external equipment.

Normal input and output are handled by the INP (74) and OUT (75) commands respectively. These operate on blocks of memory.

2. Data and Control Lines

INPUT CABLE LINES	FUNCTION
Input Data and Input Status (12 lines)	Dual Purpose: 1) As data lines they hold equipment input register contents which the computer may sample. 2) As input status lines they indicate equipment's response to status request interrogation.
Input Ready (1 line)	Indicates that the external equipment contains information which the computer may sample. (Computer resync circuits are oriented about the leading edge of the ready signal.)
Input Request	Indicates to external equipment that computer

(1 line)	[illegible] completed input [illegible]. [illegible] to [illegible] input ready.
Input Disconnect (1 line)	Indicates to computer that input device has no more data to deliver. Computer is then free to resume main program with no further delay. (Generally the input instruction establishes a storage field block of greater capacity than the anticipated input information block.)

OUTPUT CABLE LINES	FUNCTIONS
Output Data and Output Function (1[illegible] lines)	Continuously monitored by all equipment. Dual purpose: 1) As output data lines they hold output word which the external device may sample. 2) As output function lines they carry external function (EF) codes to select or sense a condition within the equipment. Function ready alerts the equipment to sample the EF code.
Function Ready (1 line)	Accompanies EF code. It is turned on by instruction [illegible] and causes the equipment to examine the EF code. It is turned off by an output resume from the external equipment.
Information Ready (1 line)	This signal accompanies the output data word from the computer and is turned on when the computer has a word of information ready for the

	external equipment. It is turned off by an output resume from the equipment.
Output Resume (1 line)	This signal is turned on when the external device has accepted the output word or EF code. (The computer resync circuitry orients itself about the trailing edge of the resume; when the signal drops the word is exchanged.) The computer prepares a word while the signal is up.
Master Clear (1 line)	This signal clears all external equipment. It occurs when the Load-Clear switch at the console is in the Clear (down) position.